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Abstract

In this study, we investigate whether irrigated agriculture results in improved child nutrition outcomes among farm households in southern Ghana. Using panel data collected between 2014 and 2015, the results from the inverse probability weighted regression adjustment (IPWRA) estimator suggest that children in households practising irrigated agriculture have, on average, higher weight-for-age and weight-for-height than those in non-irrigating households. Males and under-five children gained substantial improvements. Disaggregating irrigation by type, the results indicate that households planting on riverbeds or riverbanks have improved child nutrition. Additionally, children in households lifting water from water sources have higher height-for-age and weight-for-age. Further analysis of the underlying pathways suggests that an increase in health care financing and improvement in environmental quality, rather than decreases in illness incidence, may be the crucial channels. Altogether, the findings show the importance of investments in agricultural development, particularly in small-scale irrigated agriculture technologies, to reduce childhood undernutrition.

Key words: *Irrigated agriculture; Child nutrition; Intrahousehold allocation; Treatment effect estimators; Panel regressions*

1. Introduction

In many low and middle-income countries (LMICs), reducing undernutrition remains a primary public health goal. This is more evident in the Sustainable Development Goals (SDGs), where 12 of the 17 (about 70%) goals are related to nutrition (Scaling-Up Nutrition, 2017). Globally, undernutrition accounts for about 45% of deaths of children under five years old (Black et al., 2013). Despite several nutrition-sensitive interventions, undernutrition remains disproportionately higher in LMICs.

The health effects of child undernutrition are often irreversible and have long-term consequences. Many empirical studies show that undernutrition can impair cognitive and physical development, school performance, and labour productivity in later years (see, e.g., Humphrey, 2009; Almond and Currie, 2011). In Ghana, about 19% of children under five years old are stunted (low height-for-age z-scores), and 11% of children are underweight (low weight-for-age z-scores) (GSS et al., 2015). The prevalence of child undernutrition is higher in rural areas than in urban areas. This could be attributed to several factors, including limited infrastructure investment and high poverty levels in rural areas compared to urban areas.

Investments in agriculture are essential to enhance food and nutrition security. Agriculture employs about 38% of the labour force despite Ghana's population being increasingly urbanised, and the fact that gross domestic product (GDP) shares of the agriculture sector declined sharply over the last decade (GSS, 2019). Public investments can improve agricultural yield and productivity through knowledge transfer and infrastructure expansion (Dercon et al., 2009). In Africa, expanding irrigation technology is one of the agrarian policy goals, and is emphasized in the 2018 Malabo Montpellier Panel report (Malabo Montpellier Panel, 2018). However, public investments in agriculture remain low in many African countries. In Ghana, for example, public agricultural expenditure (% GDP) averaged about 3.3% from 2001 to 2015, significantly lower than the 10% target of the Comprehensive Africa Agriculture Development Programme (CAADP) commitment (Benin, 2019).

Previous studies have shown that irrigation technology increases production and household income. For example, by expanding irrigation technologies, households can extend the growing season (produce more than once annually) and reduce dependence on rainfed agriculture by making crop production possible in marginal land where rainfall is inadequate (Lipton et al., 2003). Irrigation also increases land productivity using an appropriate input mix, thereby generating higher farm incomes.

In addition, small-scale irrigation (SSI) using tube wells in Nigeria increased per hectare returns from 65% to 500% (Burney and Naylor, 2012), and treadle pump irrigation increased income per hectare by over 500% in Malawi (Mangisoni, 2008). Balana et al. (2020) showed that although access to SSI can significantly increase net returns in northern Ghana, the use of diesel-powered irrigation schemes generates more net income than other types of irrigation. The cost–benefit analysis, however, shows that the use of watering cans generates higher returns per capital investment, indicating potential differential impacts of irrigation technologies. Altogether, the literature suggests that SSI schemes generate the highest economic pay-offs and are more sustainable (You et al., 2011; Xie et al., 2014).

The main objective of our study was to examine the impact of irrigated agriculture[1] on child health and nutrition outcomes in southern Ghana using four rounds of panel data collected between 2014 and 2015.

A few studies have investigated the relationship between irrigation and consumption/nutrition outcomes. Alaofe et al. (2016) reported that households with irrigation increase yield and consumption of fruits and vegetables, spend more on food and healthcare services than households without irrigation. This suggests that increased income from irrigation leads to investment in productive expenditures/assets. Other studies that explore the relationship between irrigation and dietary diversity found that irrigation is positively and significantly associated with household dietary diversity and production diversity (Bhagowalia et al., 2012; Benson, 2015; Passarelli et al., 2018; Akudugu et al. 2016). Although investment in irrigation is supported to ensure food and livelihood security (e.g., Domenech, 2015), there is an ongoing debate over which types of irrigation technologies could be more nutrition-sensitive.

Irrigation technology is a key strategy to improve yield and productivity, and thereby to ensure food and nutrition security among smallholders. To that end, various types of SSI technologies have been promoted in many LMICs. The impacts of irrigation on household nutrition and health outcomes greatly depend on the scale and types of irrigation schemes. For example, homestead irrigation, typically owned by women, is used to grow vegetables for their own consumption and/or for local markets. However, in large-scale irrigation schemes, farmers produce mainly cash crops and women often do not have much control over the income (see, for example, Theis, 2016; Bryan and El Didi, 2019; Bryan and Garner, 2022).

Studies assessing the impact of irrigated agriculture on child nutrition using anthropometric measurements are few (e.g., Benson, 2015; Usman and Gerber, 2020). To the best of our knowledge, evidence on the impacts of irrigated agriculture by its type on child nutrition is also scarce and no previous study has examined the gender-differentiated impact of irrigated agriculture on child nutrition outcomes. A strong evidence base should be built for policy makers and development practitioners to guide on the design of successful programmes and facilitate the adoption of irrigation technologies. This study attempted to fill these gaps.

With the growing interest in expanding SSI in Ghana, this is an important and policy-relevant topic. With the implementation challenges encountered with the so-called "One Village: One Dam" programme, the results from this study could shed additional light by providing evidence on the nutritional benefits of SSI. Furthermore, the implementation challenges of the government's current irrigation programme make it a critical issue in terms of agricultural policy. Therefore, studying the impact of irrigated agriculture on child nutritional outcomes is a topical issue in Ghana due to the slow pace of implementation of this flagship programme and the reported complaints about the quality of completed dams (GhanaWeb, 2019). Furthermore, policy decisions require information on the types of irrigation technologies that are nutrition-sensitive, and quick implementation of the programme.

This study contributes to the literature in many ways. First, the study focuses on the effect of irrigated agriculture on child nutrition using anthropometric indicators. Previous studies (e.g., Passarelli et al., 2018; Mekonnen et al., 2019) mostly relied on food consumption diversity. Second, this study uses panel data, allowing to control for time dimension in the analysis. Other studies (e.g., Kiroge et al., 2007; Benson, 2015; Gerber et al., 2019; Usman and Gerber, 2020) have relied on cross-sectional data affected by endogeneity issues. Third, and most important, the study disaggregates the impacts based on irrigation types and gender of children, and discusses the potential pathways through which irrigated agriculture could impact child nutrition outcomes. Using four rounds of panel data collected between 2014 and 2015 in southern Ghana and employing the inverse probability weighted regression adjustment (*IPWRA*) estimator, the findings were that children living in irrigating households had, on average, higher weight-for-age and weight-for-height than children residing in non-irrigating households. The results are robust to various model specifications and alternative estimation approaches.

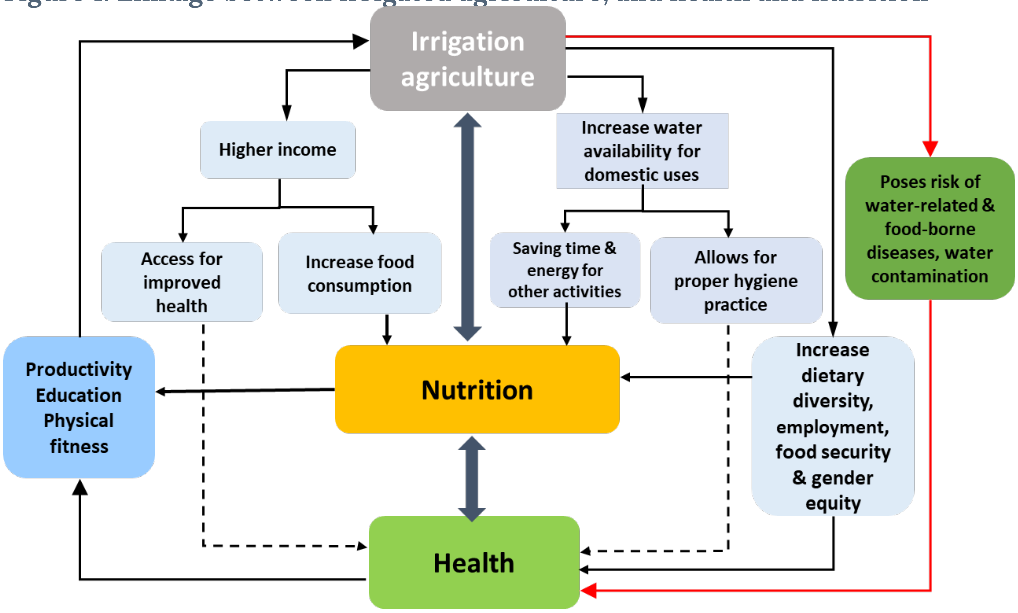
2. Conceptual Framework

Irrigation can affect health and nutrition outcomes through several pathways (see Figure 1). The adoption of different types of irrigation could affect children's nutrition outcomes in diverse ways[2]. Irrigation can cause adverse impacts on the environment and human health if it is poorly planned or designed. Irrigated agriculture can influence health negatively through increased water-related diseases and domestic water contamination (Gerber et al., 2019; Usman and Gerber, 2019; Usman et al., 2019). Irrigation systems can exacerbate the incidence of waterborne diseases and other illnesses, by creating suitable conditions for the propagation of disease vectors, such as mosquitoes (Asayehegn, 2012; Asenso-Okyere et al., 2012). Irrigated agriculture could nonetheless increase productivity, production diversity, and improve food availability, allowing households to improve their nutrition and household income (von Braun et al*.,* 1989; Passarelli et al., 2018; Adela et al., 2019; Nonvide, 2018). Moreover, the increased income associated with irrigated agriculture can enable a given household to access improved healthcare services and, in turn, improve the health and nutrition outcomes of household members.

Domestic water quality and quantity may also be affected by irrigation practices. Interestingly, irrigation schemes increase the availability of water for domestic purposes where multiple-use water systems are common (van der Hoek et al. 2001; van der Hoek et al. 2002).

Irrigation serves as a source of drinking water in many developing countries where access to improved drinking water sources is inadequate (van Der Hoek et al*.,* 2001; van der Hoek et al. 2002; Usman et al*.,* 2018). Increasing water availability for domestic purposes helps households meet basic hygiene needs, improving health outcomes associated with water quantity (van Der Hoek et al*.,* 2001). Moreover, where access to improved drinking water supply is inadequate, increasing water availability reduces the burden of water collection time, which is often disproportionately borne by women and girls, and can save time and energy for other income-generating activities, such as agricultural production, as well as social activities such as child-caring (Sorenson et al., 2011), with direct and indirect health consequences. A review by Domenech and Ringler (2013) synthesized the available evidence on the impacts of irrigation on health, nutrition and women empowerment in sub-Saharan Africa.

Figure 1: Linkage between irrigated agriculture, and health and nutrition



Source: Usman (2017).

3. Methods

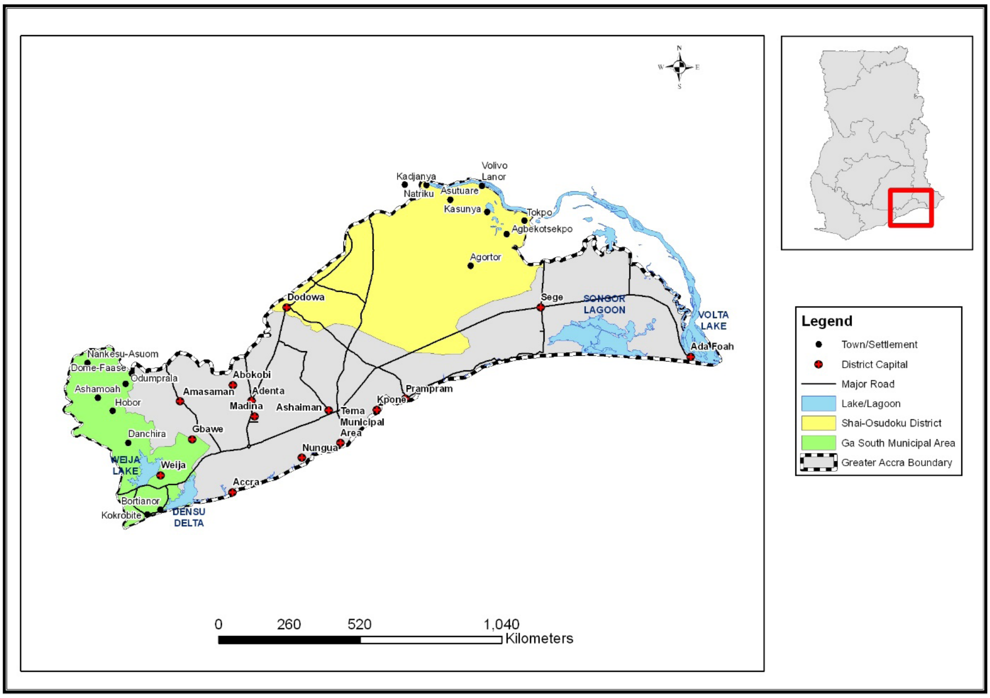
3.1. Data

This study relied on four rounds of geographic-specific surveys collected from April 2014 to June 2015. The sample households were selected using a stratified cluster sample design (for detailed information, see Okyere, 2018). Informed consent was obtained for participating households. The survey instruments for the baseline data (April/May 2014) collected height and weight measurements for children under eight years of age, detailed information on agricultural activities, irrigated agriculture, productive assets, income, healthcare expenses, household consumption expenditures and other socio-economic characteristics. This survey instrument was repeated for the endline survey in May/June 2015. The other two survey waves (i.e., first follow-up (November/December 2014) and second follow-up (January/February 2015)) used an abridged version of the baseline survey instrument with anthropometric measures, information on income, healthcare expenses, irrigated agriculture and other agricultural activities, but without the detailed consumption expenses and productive assets information.

Having child-level anthropometric measures, together with irrigated agriculture activities and detailed household socio-economic characteristics, presents the opportunity to examine the potential mechanisms. According to Kirk et al. (2018), the short duration between the survey waves allows controlling for time-constant child characteristics, which could not be addressed using cross-sectional data.

The household survey was conducted in Ga South Municipal (urban) and Shai-Osudoku (rural) districts in the Greater Accra Region. From the urban district, only rural and peri-urban communities (which are similar to those in the rural district) were targeted in the sample selection. The main focus of this study was children in agricultural households. However, children from non-agricultural households were included due to the relatively smaller sample size for the study. We restricted the analysis to children with anthropometric measures in the baseline survey or to those born after the baseline survey (see Kremer et al., 2011). The final analysis comprised 1,317 child observations across the four survey waves: 318, 331, 392 and 276 child observations in April/May 2014, November/December 2014, January/February 2015 and May/June 2015 respectively. Of these, 41.6% in all the four surveys, 32.6% in three survey waves, 16.9% in any two survey waves and 9% in only one survey wave, were observed. Figure 2 is a map of the study areas. Finally, the sample was representative neither at the national nor at the district level. The study sites were selected purposely based on *ex ante* information. Therefore, the results may not be generalised to the whole population. While we acknowledge that the sample size was small, alternative panel data sets are lacking for Ghana (to the best of our knowledge) containing anthropometrics with representative samples for children in both irrigated agriculture and non-irrigated agriculture households. In Ghana, access to irrigation is extremely low. For example, the Africa *RISING* baseline evaluation survey (ARBES) report, a nationally representative survey in Ghana, showed that 3% of the sampled households reported irrigating their land (Tinonin et al., 2016). Similarly, various types of irrigation technologies exist in the country but less than 2% of arable lands are under irrigation (Mendes et al., 2014). These include human-powered, rope and treadle pumps to liquid fuel engine-driven systems and solar-powered pumps as well as gravity and river diversion methods (Akrofi et al., 2019).

Figure 2: Map of the study areas



Source: Okyere (2018)

This study used unbalanced panel data, with some of the children not measured in all the survey rounds. Accordingly, the results may suffer from attrition bias. Although we controlled for survey round fixed effects in the analyses, the attrition rate, if systematic and affects one group more than the other, could lead to potential upward estimation bias. We undertook an analysis of the attrition rate, and found it similar for both irrigators and non-irrigators (Appendix A). For example, we analysed the level of attrition rate based on children with only one observation and older than 12 months of age in the baseline data, following Kirk et al. (2018). The attrition rate was unaffected by the adoption of irrigated agriculture. Furthermore, the results did not change by defining attrition either to mean children with 1 or 2 observations and older than 12 months of age in the baseline data, or to mean children with only 1 or 2 observations in the data.

3.2. Estimation strategy

Anthropometrics measures, such as height-for-age z-scores (HAZ), weight-for-age z-scores (WAZ), and weight-for-height z-scores (WHZ), were used as indicators of child nutrition. The use of anthropometrics, which is recommended by the World Health Organization (WHO) for child nutrition measures, is scarce in the literature on the impacts of irrigated agriculture. Anthropometrics measurements are objective indicators and less subject to measurement errors than alternative nutritional indicators such as dietary diversity and calorie intakes, which are mainly based on recall by the respondent and prone to recall bias. The study was based on a random utility framework, where a household adopted irrigation technologies to maximise its utility (i.e., child nutrition) by comparing it to the utility from non-irrigating households. Furthermore, closely following Grossman (1972) and Mangyo (2008), this study conceptualised the nutrition of children as a stock, implying that the current level of child nutrition is affected by both current and previous inputs, including investments in irrigated agriculture. The econometric model for the nutrition production function was specified in its basic form as:

$$N_{ijt} = \propto + \emptyset IA_{jt} + \rho H_{jt} + \mu C_{ijt} + \omega V_{ijt} + W_t + D_c + \varepsilon_{ijt} \quad (1)$$

where i represents child, t indicates survey waves ($t \in 0,1,2,3$), j indicates household, and IA a dummy variable indicating household participation in irrigated agriculture. N represents child nutritional outcomes, and H represents the household. C represents the child and V represents community-level characteristics. W_t and D_c capture survey wave and district fixed effects respectively, and ε represents the error term; $\propto$, $\emptyset$, ρ, μ and ω are the estimated coefficients.

Assessing the impact of irrigated agriculture on child nutritional outcomes (HAZ, WAZ and WHZ) is challenging due to several reasons, including inadequate data and methodological issues. One of the main challenges of evaluating the impact of irrigated agriculture based on observational data is the estimation bias due to the non-random participation in irrigated agriculture, and the self-selection of households into adopting irrigation technology. Hence, irrigation technology is not assigned randomly, and households may decide whether to adopt irrigation depending on observed and unobservable factors. For example, if resource-endowed farmers are more likely to participate in irrigated agriculture, impact assessments that fail to account for such household characteristics adequately will lead to biased estimates (for discussion on impact evaluation of infrastructure, see Dercon et al., 2009). We assumed that different types of irrigation would be based on different levels of water availability and, consequently, different levels of productivity. For example, descriptive statistics from this study context showed that different types of irrigation lead to choices of different crops, land allocation, and also income (refer to Section 4.3).

Furthermore, undernutrition is caused by several factors, including the environment. Previous studies have shown that the benefits of high-quality foods on nutrition could be eroded by poor environmental quality such as unsafe drinking water, inadequate sanitation, and poor hygiene practices (e.g., Zhang, 2012; Wolf et al*.,* 2014). All these factors could affect the validity of the estimated impact, notably if these factors are correlated with irrigated agriculture.

This study focused on estimating the impact of irrigated agriculture and its types on child nutritional outcomes. As discussed previously, participation in irrigated agriculture is non-random. We therefore used the *IPWRA* estimator, where both outcome and treatment models are specified to address the non-random participation in irrigated agriculture. The treatment effect is obtained using weighted regression coefficients, where the weights are generated from the inverse probabilities of the treatment (Wooldridge, 2010). The *IPWRA* estimator accounts for the misspecification in either the outcome or treatment models, thereby generating a robust estimate of the impact of irrigated agriculture based on the observable characteristics (Cattaneo, 2010; Manda et al., 2018). However, one of the main limitations of *IPWRA* is that it does not consider selections based on unobservable characteristics.

Based on the estimated inverse-probability weights, weighted regression models for the outcome were fitted using a logit model to generate the expected outcomes of the probabilities of participation and non-participation in irrigated agriculture. The independent variables were selected based on previous studies on the factors influencing the adoption of irrigation technologies, and the availability of information (see Tables 1 and 3 for variables included in the models). The difference between the computed mean outcomes of participants and non-participants provides estimates of the treatment effects of irrigated agriculture (see Manda et al., 2018; Tambo and Mockshell, 2018). The study relied on *teffects ipwra* in Stata version 14.2 (StataCorp, 2015) for the data analysis.

In the preferred estimator of *IPWRA* complemented with propensity score matching (PSM), the study analysed both the average treatment effect (ATE) and average treatment effects on the treated (ATT). The ATT can be obtained with the following mathematical representation:

$$ATT^{IA_p|IA_0} = E\{N^{IA_p} - N^{IA_0}|T = IA_p\} = E\{N^{IA_p}|T = IA_p\} - E\{N^{IA_0}|T = IA_0\},\ T \in \{0, 1\} \qquad (2)$$

where $E\{.\}$ is the expectation operator; IA_p indicates the adoption of irrigated agriculture; IA_0 denotes non-irrigated agriculture; N^{IA_p} and N^{IA_0} represent the nutritional outcomes of a child for irrigating and non-irrigating households respectively; and T is a dummy variable indicating if a household engaged in irrigation agriculture (=1 if irrigating household, 0 otherwise). We performed several sensitivity analyses to check the validity of the estimates, including PSM, Heckman selection model, fixed effects (FE), random effects (RE), and correlated random effects (CRE) estimators.

4. Results and Discussion

4.1 Descriptive statistics

Table 1 presents the summary statistics on irrigated agriculture practices. The results provide some perspective on the econometric results presented later in this section. Agriculture is the main livelihood activity in the study area. Fewer than one-quarter (i.e. 23.4%) of the households engaged in irrigated agriculture. On a broader classification of irrigation based on technologies involved in applying water to crops, 27.6% of the households undertook "natural irrigation", whilst 22.2% relied on "artificial irrigation"[3]. The most commonly practised (22.3%) irrigation technology was access to water from various water sources, followed by cultivating on low-lying, swamps or marshland (19.2%), and then other types of irrigation, including drip irrigation, surface irrigation, among others (13.6%). About 6.3% of the households applied overhead irrigation using a watering can or bucket. Sprinkler irrigation (3.3%) was less widespread in the study area. On average, families spent three and a half days each week on irrigated fields. The average irrigable farm size was 1.3 hectares, and the average income from irrigated agriculture was 1,398 Ghanaian cedis (GHC) (equivalent to USD466). Over half the sampled households depended entirely on family labour for irrigated agriculture. Household members responsible for irrigation experienced health problems, such as body pains (86.1%), injury (48.1%), malaria (38%) and respiratory diseases (25.3%) in the preceding 4 weeks before the survey.

Table 1: Irrigated agriculture practices in the study area

Variable	Mean	SD	N
Treatment variables			
HH engages in agriculture — Yes = 1	0.855	0.352	1,317
HH participates in irrigated agriculture — Yes = 1	0.234	0.423	1,314
Irrigation types (only in baseline & end line surveys)			
Cultivate on low-lying, swamp/marsh land	0.192	0.394	589
Plant crops on riverbeds/riverbanks	0.119	0.324	588
Access to water in a dam/canal/river/lake for irrigation	0.223	0.416	588
Water from dam, canal, river or lake	0.082	0.274	587
Access to water pump	0.088	0.284	577

Sprinkler irrigation	0.033	0.179	574
Overhead irrigation using a watering can/bucket	0.063	0.243	574
Any other type of irrigation	0.136	0.343	572
Natural irrigation	0.276	0.447	594
Artificial irrigation	0.222	0.416	594
Irrigated agriculture practices at baseline			
Number of days spent on irrigation fields in the past 7 days	3.357	2.462	70
Total irrigable farm size in hectare	1.339	0.668	79
Income from irrigation in the last farming season (GHC)	1,397.77	1,384.40	72
Source of labour for irrigated agriculture			
Hired labour	0.176	0.383	74
Family labour	0.527	0.503	74
Both family & hired labour	0.297	0.460	74
Major health problems [a]			
Injury (blisters, cuts etc.)	0.481	NA	79
Body pains	0.861	NA	79
Malaria	0.380	NA	79
Respiratory diseases	0.253	NA	79
Dermatological diseases (skin diseases)	0.190	NA	79

Notes: NA = not available; HH = household; [a] percentage of cases reported because of multiple responses.

Reported in Table 2 are child nutritional outcomes by irrigation status, and the results show that irrigating households had better child nutrition than non-irrigating households (column 3). Except for HAZ, mean differences in children's WAZ and WHZ were statistically significant between irrigating and non-irrigating households. The main caution with this result is that it is merely a correlation and not suggestive of the impact of irrigated agriculture. Summary statistics of the outcome variables by the survey waves are reported in Appendix B.

Table 2: Summary statistics of the outcome variables

Variable	(1) Irrigating HH Mean [SD]	(2) Non-irrigating HH Mean [SD]	(3) Mean Difference [SE]
Height-for-age z-scores	-0.971	-1.027	0.056
	(1.405)	(1.260)	(0.086)
Weight-for-age z-scores	-0.649	-0.865	0.217***
	(1.147)	(1.113)	(0.075)
Weight-for-height z-score	-0.234	-0.432	0.198**
	(1.316)	(1.267)	(0.092)
Observations	308	1,006	

Notes: *** and ** denote 1% and 5% statistical significance level respectively. Overall, 20.7% children were stunted, 12.9% underweight, and 6.8% wasted.

Based on previous empirical studies (e.g., Abdulai et al., 2011), we included a wide range of child, parental, household and community-level characteristics in the empirical models. Several of these variables are important determinants of child health and nutrition outcomes. As shown in Table 3, about 80% of the household heads were male with low educational qualifications (65.3% with no formal education). Access to the Internet was deficient (11.6%), but access to environmental quality indicators was moderately high. According to the WHO Joint Monitoring Programme (JMP) classifications, 68% of the households have access to improved water supply and 44% have access to improved sanitation. One-fifth of the households treated water to make it safer for consumption. Further, most households lived in communities with water bodies. Half the children were males and biological children of household heads (75%). The self-reported prevalence of diarrhoea among children was low, while fever was relatively high (15.4%).

Table 3 provides summary statistics by irrigation status. The results suggest that irrigated households were relatively male-headed and more educated, had significantly better access to the Internet and improved drinking water, high monthly income, more extension visits, high presence of cooperative or farmer group organisations and owned more agricultural land than non-irrigated agriculture households. However, non-irrigated households owned larger herds of livestock than irrigated households. On children's characteristics, both groups were comparable in terms of age, gender, and relationship to household head; except for healthcare financing and malaria prevalence. Lastly, imbalances in summary statistics for observational studies are common in the empirical literature. In Zeweld et al. (2015), for example, 7 out of the 11 variables were statistically different at the conventional significance level. Similarly, in Pasarelli et al. (2018) 13 out of 21 (for Ethiopia data) and 17 out of 21 variables (for Tanzania data) were statistically different from each other.

Table 3: Summary statistics by irrigation status

	Full sample	**Irrigated agriculture**	**Non-irrigated agriculture**	**Mean difference**
Variable	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	
HH head age in years	46.69 (10.82)	46.13 (9.03)	46.85 (11.27)	-0.72
HH head is a Christian	0.78 (0.42)	0.87 (0.34)	0.75 (0.43)	0.11***
Male headed HH	0.80 (0.40)	0.87 (0.34)	0.78 (0.41)	0.08***
Head's married	0.75 (0.43)	0.75 (0.43)	0.75 (0.43)	0.00
Head's ethnicity is Ga/Adangbe (native)	0.44 (0.50)	0.47 (0.50)	0.43 (0.50)	0.03
Head's no formal educational qualification	0.65 (0.48)	0.63 (0.49)	0.66 (0.47)	-0.04
Head's MSLC/BECE	0.25 (0.43)	0.22 (0.42)	0.26 (0.44)	-0.04
Head's SSSC or beyond	0.10 (0.30)	0.15 (0.36)	0.08 (0.27)	0.07***
HH has access to the internet	0.12 (0.32)	0.15 (0.36)	0.10 (0.31)	0.05**
Number of female HH members (≥15 years)	2.04 (1.12)	2.08 (1.18)	2.03 (1.09)	0.06
HH size	7.95 (2.90)	7.96 (2.99)	7.95 (2.87)	0.01

HH has improved drinking water source	0.68 (0.47)	0.72 (0.45)	0.66 (0.47)	0.06*
Minutes to the primary drinking water source	12.06 (12.72)	10.77 (13.49)	12.20 (12.34)	-1.43*
HH has improved sanitation	0.44 (0.50)	0.47 (0.50)	0.43 (0.49)	0.04
HH disposes liquid waste on the compound	0.64 (0.48)	0.63 (0.49)	0.64 (0.48)	-0.01
HH treats water	0.19 (0.391	0.20 (0.40)	0.19 (0.39)	0.01
HH has improved solid waste disposal [a]	0.18 (0.38)	0.20 (0.40)	0.17 (0.38)	0.03
HH has electricity from the national grid	0.77 (0.42)	0.82 (0.39)	0.76 (0.43)	0.06**
HH resides in an urban district	0.46 (0.50)	0.43 (0.50)	0.47 (0.50)	-0.04
HH uses bed nets for malaria control	0.89 (0.32)	0.88 (0.33)	0.89 (0.32)	-0.01
Bednet per capita	0.42 (0.20)	0.40 (0.20)	0.42 (0.20)	-0.02
HH monthly income is high (>GHC400)	0.48 (0.50)	0.54 (0.50)	0.46 (0.50)	0.08**
Baseline characteristics				
Road to the community was tarred	0.11 (0.31)	0.09 (0.28)	0.11 (0.32)	-0.03
Presence of water bodies in the community	0.77 (0.42)	0.83 (0.38)	0.74 (0.44)	0.10***
Extension visits to the community	0.19 (0.38)	0.31 (0.46)	0.13 (0.34)	0.17***
Presence of cooperative in the community	0.10 (0.29)	0.22 (0.42)	0.08 (0.27)	0.14***
HH owned large livestock	0.10 (0.30)	0.07 (0.25)	0.11 (0.32)	-0.04**
HH owned agricultural land	0.62 (0.49)	0.68 (0.47)	0.60 (0.49)	0.08**
HH had off-farm business activity	0.62 (0.49)	0.66 (0.48)	0.60 (0.49)	0.05
HH owned a house	0.65 (0.48)	0.70 (0.46)	0.64 (0.48)	0.06**
HH had savings with financial institutions	0.48 (0.45)	0.58 (0.49)	0.44 (0.49)	0.14***
Periodic market in the community -Yes=1	0.11 (0.31)	0.15 (0.35)	0.07 (0.25)	0.08***
Child characteristics				
Child age in months	54.68 (24.31)	53.47 (24.05)	55.09 (24.39)	-1.62
Child is male	0.51 (0.50)	0.48 (0.50)	0.52 (0.50)	-0.04
Biological child of the HH head	0.75 (0.43)	0.78 (0.41)	0.74 (0.44)	0.04
Child had illness/injury in the past 4 weeks	0.27 (0.44)	0.30 (0.46)	0.26 (0.44)	0.04
Child had diarrhoea in the past 4 weeks	0.06 (0.23)	0.05 (0.22)	0.06 (0.24)	-0.01
Child had fever in the past 4 weeks	0.15 (0.36)	0.20 (0.40)	0.14 (0.35)	0.05**
Child has valid National Health Insurance card	0.25 (0.43)	0.25 (0.44)	0.25 (0.43)	0.01
Child ever had NHIS card	0.49 (0.50)	0.56 (0.50)	0.48 (0.50)	0.08**
Observations	1314	308	1,006	

***Notes**:* Missing values in some of the baseline indicators are replaced with the community averages;

[a] Use of public dump/garbage centre or collection by a local authority/a private firm; Statistical significance denoted at: *** p<0.01, ** p<0.05, * p<0.1.HH denotes household; BECE indicates basic education certificate examination; MSLC represents middle school leaving certificate and SSSC indicates senior secondary school certificate; NHIS denotes National Health Insurance Scheme.

4.2 Econometric Results

4.2.1 *Factors influencing adoption of irrigation technologies*

In this section, we first present the empirical results from logit regressions (Table 4), which are used to predict the treatment status, that is, the factors influencing a household's decision on whether to adopt irrigated agriculture. Column 1 presents a pooled logit model (without considering the panel structure of the data). Columns 2 and 3 report the RE logit models (considering the panel structure of the data, but without including unobserved heterogeneity). The last two columns (4 and 5) summarise the estimates of CRE models, which consider both the panel nature of the data and unobserved heterogeneity (Mundlak, 1978; Liverpool-Tasie, 2017; Tambo et al., 2020). The results from column (4), our preferred model with clustered standard errors, suggest that household access to the Internet, agricultural extension visits to the community, and the presence of cooperatives in the community, are more likely to increase household adoption of irrigated agriculture (column 4, Table 4). These results partly confirm those from previous studies (e.g., Abdulai et al., 2011) on the socio-economic correlates of irrigation. All these variables could improve household access to information related to agricultural technologies, which can increase the likelihood of households adopting irrigation technology. Ownership of farmland, presence of water resources, and the religion of household head being Christian, were also positively associated with irrigation adoption. The result on religion is not surprising, as Ghana is predominantly Christian (about 71% based on the 2010 Population and Housing Census; GSS, 2012). This also partly confirms results from previous studies (Tanko and Ismaila, 2021) on the importance of integrating religion in the dissemination of technologies to improve agricultural productivity. Furthermore, a study by Auriol et al. (2020) showed the role religion (particularly Christianity) plays in terms of resource allocation in Ghana. Therefore, the plausible explanation on religion affecting irrigation adoption could be the importance of religion in supporting social networks, which facilitates resource allocation, including irrigation services in the study area. However, ownership of livestock was negatively and significantly associated with irrigation adoption. Regression results in the other columns show the importance of different institutional and socio-economic characteristics in influencing the decision of households to undertake irrigated agriculture.

Table 4: Estimates for factors influencing participation in irrigation

	Pooled Logit	RE Logit	RE Logit	CRE Logit	CRE Logit
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Male headed HH	0.630***	0.770	0.770	0.748	0.748
	(0.239)	(0.473)	(0.590)	(0.607)	(0.473)
Head's age	0.010*	0.124	0.124	0.113	0.113
	(0.052)	(0.096)	(0.127)	(0.288)	(0.312)
Squared of head's age	-0.001**	-0.001	-0.001	-0.001	-0.001

	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)
Head's no formal educational qualification (ref. group)					
Head's MSLC/BECE	-0.368**	-0.782**	-0.782*	-0.726	-0.726**
	(0.183)	(0.363)	(0.448)	(0.442)	(0.363)
Head's SSSC or beyond	0.140	0.168	0.168	0.356	0.356
	(0.251)	(0.528)	(0.670)	(0.676)	(0.529)
Head's ethnicity is Ga/ Adangbe (native)	-0.169	-0.256	-0.256	-0.207	-0.207
	(0.162)	(0.334)	(0.473)	(0.472)	(0.334)
HH has electricity from the national grid	0.437**	0.721**	0.721	0.679	0.679**
	(0.196)	(0.340)	(0.450)	(0.448)	(0.339)
HH resides in an urban district	0.423**	0.482	0.482	0.547	0.547
	(0.191)	(0.393)	(0.526)	(0.530)	(0.393)
Household size	-0.282***	-0.427**	-0.427	-2.166***	-2.166***
	(0.096)	(0.188)	(0.273)	(0.742)	(0.798)
Squared of household size	0.0101**	0.0169**	0.0169	0.117***	0.117***
	(0.004)	(0.008)	(0.013)	(0.035)	(0.041)
Household has access to internet	0.679***	1.200***	1.200***	1.017**	1.017***
	(0.224)	(0.365)	(0.453)	(0.453)	(0.372)
Number of female HH members (≥15 years)	0.110	0.174	0.174	0.250	0.250
	(0.083)	(0.159)	(0.193)	(0.199)	(0.161)
Head's married	-0.457**	-0.480	-0.480	-0.468	-0.468
	(0.189)	(0.402)	(0.546)	(0.554)	(0.401)
Head's Christian	1.033***	1.485***	1.485***	1.486***	1.486***
	(0.218)	(0.420)	(0.527)	(0.542)	(0.423)
Baseline characteristics					
Road to community was tarred	-0.713***	-1.216**	-1.216	-1.161	-1.161**
	(0.266)	(0.553)	(0.814)	(0.814)	(0.550)
Presence of water bodies in the community	0.694***	0.913**	0.913*	0.851*	0.851**
	(0.201)	(0.400)	(0.512)	(0.504)	(0.398)
Extension visit to the community	1.163***	1.882***	1.882***	1.844***	1.844***
	(0.199)	(0.450)	(0.541)	(0.537)	(0.448)
Presence of cooperative in the community	0.937***	1.436***	1.436**	1.454**	1.454***
	(0.232)	(0.522)	(0.630)	(0.627)	(0.520)
Presence of periodic market in the community	0.0194	0.245	0.245	0.257	0.257
	(0.241)	(0.502)	(0.683)	(0.683)	(0.499)
HH owned large livestock	-0.637**	-1.301**	-1.301	-1.159	-1.159*
	(0.303)	(0.617)	(0.858)	(0.857)	(0.615)
HH owned agricultural land	0.573***	0.849**	0.849*	0.867*	0.867**

	(0.183)	(0.380)	(0.483)	(0.488)	(0.379)
HH had off-farm business activity	0.0503	0.215	0.215	0.185	0.185
	(0.164)	(0.340)	(0.453)	(0.453)	(0.340)
HH owned house	0.393**	0.634*	0.634	0.636	0.636*
	(0.164)	(0.349)	(0.489)	(0.493)	(0.348)
Constant	-4.825***	-6.960***	-6.960**	-7.735**	-7.735***
	(1.288)	(2.490)	(3.142)	(3.346)	(2.691)
Survey fixed effects	Yes	Yes	Yes	Yes	Yes
Clustered standard errors at the HH level	No	No	Yes	Yes	No
Mean of time-varying variables included	No	No	No	Yes	Yes
Observations (children-wave)	1,293	1,293	1,293	1,293	1,293
Number of children	-	507	507	507	507
Prob > Chi²	0.000	0.000	0.003	0.001	0.000
Pseudo R^2	0.135	-	-	-	-

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; mean of time-varying variables such as age and its squared of household head, and household size and its squared are included in the CRE estimates.

4.2.2 Impacts on nutrition outcomes

The impact of irrigated agriculture on child nutrition outcomes is summarised in Table 5. The estimated coefficients are from the doubly robust IPWRA estimator, and the treatment models are specified using the covariates reported in Table 4. We performed several diagnostic tests for the IPWRA and PSM estimators. We found the model specifications can balance the covariates and samples in the data. The estimated density of the predicted probabilities displayed in Appendix Figure C1, and the two estimated densities have more of their respective masses in the regions where they overlay each other, although both plots are relatively skewed to the right. For example, we failed to reject the null hypothesis that the IPWRA model balanced the covariates included in the regression with a p-value of 0.39, suggesting that the overlap assumption may not be violated. Relatedly, the covariance balance summary suggests that matching on the estimated propensity score balanced the covariates, that is, the variance ratios for all the variables are close to one, while the standardised difference is close to zero (Appendix Table C1). Therefore, the results show that once we control for covariates/propensity scores, the probability of treatment is random among irrigator and non-irrigator households. Although the treatment effect estimator has its limitation, casual inferences of IPWRA or other matching methods are common in the empirical literature (see, for example, Zeweld et al., 2015; Manda et al., 2018; Tambo and Mockshell, 2018), particularly so when further diagnostics statistics support that the models satisfactorily address selection bias.

In all our regressions, we reported both the ATE and the ATT for comparisons. Our preferred estimation is, however, the ATT, which is relevant in the context of an impact evaluation where selection into the treatment may be important. The results suggest the effect of irrigated agriculture on HAZ is positive and statistically significant at the 5% level for male children. Similarly, the estimated impact of WAZ is statistically significant. For example, the weight of children in irrigating households was, on average, 0.23 units of SD[4] higher than that of children living in non-irrigating households, and this effect was even larger for male children (column 4, Panel B, Table 5). When disaggregating the sample by age groups, the estimated effect of irrigated agriculture was still large and positive, and statistically significant at the conventional significance levels. The results further revealed that the WHZ of children from irrigating households was, on average, 0.27 units of SD more than for children from non-irrigating households. The differential impact of irrigated agriculture on WHZ was larger and stronger for children aged between 0 and 4 years (column 2, Panel B, of Table 5).

Table 5: Effects on child nutrition outcomes

Dependent variable:	**Full sample (1)**	**Ages 0–4 (2)**	**Ages 5–8 (3)**	**Males (4)**	**Females (5)**
Panel A: ATE					
Height-for-age z-scores (HAZ)	0.034 (0.096)	0.067 (0.104)	-0.212 (0.149)	-0.065 (0.154)	0.100 (0.094)
Weight-for-age z-scores (WAZ)	0.260*** (0.081)	0.222** (0.092)	0.003 (0.113)	0.280** (0.114)	0.187* (0.111)
Weight-for-height z-scores (WHZ)	0.319*** (0.099)	0.129 (0.098)	0.333** (0.155)	0.411** (0.163)	0.077 (0.129)
Panel B: ATT					
HAZ	0.066 (0.112)	-0.044 (0.154)	0.130 (0.137)	0.433** (0.189)	-0.220* (0.129)
WAZ	0.230*** (0.086)	0.217* (0.126)	0.217* (0.120)	0.404*** (0.141)	0.032 (0.124)
WHZ	0.272*** (0.098)	0.315** (0.133)	0.201 (0.170)	0.191 (0.151)	0.219+ (0.138)
Observations	**1,214**	**651**	**568**	**617**	**597**
District dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Survey round dummies	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; the treatment models include all variables reported in Table 4. The treatment model is specified using the following variables: head's gender, age and its squared term, head's level of education, religion, marital status, ethnicity, HH has electricity from the national grid, urban district, HH size and its squared term, the number of female HH member ≥15 years and HH has access to the Internet. The model is also controlled for the following characteristics at baseline: the road to community was tarred, presence of water bodies in the community, extension visit to the community, presence of cooperative in the community, presence of periodic market in the community, HH owned large livestock, agricultural land, had off-farm business activity, owned house and survey fixed effects. The outcome model is specified using all the variables included in the treatment model in addition to child characteristics and other environmental variables. Child-specific characteristics include the age of a child in months and age squared, gender and the child being a biological offspring of the HH head. The environmental variables include HH use of improved drinking water and improved sanitation, the surroundings were observed to be clean/average by data enumerator, and the time taken to the main drinking water source. Missing data will affect the number of observations for each dependent variable.

4.3 Differential effects of irrigated agriculture on child nutrition outcomes

We also examined whether different types of irrigation had varying impacts on child nutritional outcomes. To test that, we estimated the same outcome variables based on irrigation types. The results are summarised in Table 6. The estimation strategy compares the various types of irrigation to those not using that specific type of irrigation. The analyses assumed that the different irrigation types are mutually exclusive, although, in reality, farmers adopt multiple irrigation options, particularly those involving low technology options. We did this mainly for practical and methodological reasons. The technologies involved were many and the data were too few to allow us to undertake complex analysis of the combination of the irrigation options (for analyses of combining agricultural technologies, see Biru et al. (2020). Unfortunately, we did not have additional irrigation type-specific information that could be used to address the above shortcomings. Moreover, some of the irrigation methods relied on similar technologies. Including dummies of these other types would not be an appropriate exercise from an estimation point of view (as they are highly correlated). Controlling for the covariates should be, however, adequate to generate relevant evidence. A comprehensive analysis of the impacts of different irrigation technologies is an avenue for future research. However, the estimation approach we used is relevant as it presents evidence of the differential impacts of irrigated agriculture on child nutrition outcomes. We first grouped the different irrigation types into natural and artificial based on the technology involved in the utilisation of water for agricultural purposes. Our results show that under this categorisation, both natural and artificial irrigation improve weight-for-age z-scores of children even though artificial irrigation generates larger effects than natural irrigation.

We proceeded to analyse the effects of different irrigation options on children's nutrition outcomes. Our findings suggest that having irrigated fields in the community is positively and significantly associated with all child nutritional indicators except HAZ. For example, the ATT estimates suggest that the WAZ of children with irrigated fields in the community was 0.34 units of SD higher than their counterparts. This partly confirms the results from previous studies on the local economy or distributional effects of irrigation (van den Berg and Ruben, 2006; Filipski et al., 2013). Similarly, households cultivating on low-lying, swamp/marshland showed positive impacts on child nutritional outcomes (Panel B of Table 6). As can be seen, the differential effects of different irrigation types on child nutritional outcomes were generally robust. Although the estimated ATT for drawing water from dams/canals/rivers/lakes were positive across for the different nutritional indicators, the coefficients were not significant statistically (Panel D, Table 6). Note that the ATE estimate was enormous and estimated imprecisely, which might be due to the small number of samples in this group. For example, about 8% of the samples fell in this group, and a higher height-for-age than for their counterparts could drive this result. Although we are interested in the ATT estimates, the ATE result in Panel D should be treated with caution. We also observed that the estimated coefficients of the ATT of the presence of irrigated fields in the community and cultivation on low-lying, swamp/marshland did not have a significant impact on HAZ (long-term nutritional indicators). In contrast, the riverbeds/riverbanks irrigation type did not have a considerable effect on WHZ (Table 6).

An essential policy question is why different types of irrigated agriculture should lead to differential impacts on nutrition. The plausible explanation is that in this study context, similar to previous studies (e.g., Zeweld et al., 2015; Passarelli et al., 2018; Balana et al., 2020), different types of irrigated agriculture use different technologies with the associated differences in crops planted, productivity, returns and cost implications. For example, planting on riverbeds/riverbanks does not involve a large cost for irrigation, but this traditional approach is important as it allows for access to water by crops during climatic stress/variability. The key result is that the adoption of low-cost SSI generates differential impacts on child nutrition outcomes in this study context. Additional descriptive analyses from the baseline survey data show that there are differences in crops planted and income from the different types of irrigation, and these may be influencing the differences in child nutrition outcomes. For example, households cultivating on low-lying, swamp/marshland mainly planted: okro (55.93%), pepper (42.37%), rice (33.90%) and maize (28.81). Besides, the average income from irrigated agriculture for this group was GHC1,457.12, although the income from irrigated agriculture was on average about GHC678.44. For households relying on overhead irrigation, the following were the major crops: pepper (60%), okro (50%), rice (15%) and maize (5%). Major crops planted by those using riverbeds/ riverbanks were okro (70%), maize (50%), pepper (43.33%) and rice (20%). Income from irrigated agriculture for this group was GHC1,348. These results suggest that households using different types of irrigation cultivate either cereals and/ or vegetables as their major crops, and this leads to differences in income.

Table 6: Differential effects of irrigated agriculture on child nutrition

Types of irrigated agriculture	(1)	(2)	(3)
	HAZ	WAZ	WHZ
Panel A: Natural irrigation			
ATE (Yes vs. No)	0.142	0.261**	0.172
	(0.153)	(0.122)	(0.139)
ATT (Yes vs. No)	0.036	0.149	0.206
	(0.146)	(0.120)	(0.155)
Panel B: Artificial irrigation			
ATE (Yes vs. No)	0.118	0.329***	0.011
	(0.153)	(0.126)	(0.156)
ATT (Yes vs. No)	0.062	0.236*	0.192
	(0.158)	(0.132)	(0.153)
Panel C: Irrigated fields in the community			
ATE (Yes vs. No)	-0.091	0.192*	0.489***
	(0.127)	(0.105)	(0.155)
ATT (Yes vs. No)	0.019	0.343***	0.648***
	(0.136)	(0.130)	(0.198)
Panel D: Cultivate on low-lying, swamp/marshland			
ATE (Yes vs No)	0.303**	0.334***	-0.100
	(0.153)	(0.121)	(0.148)
ATT (Yes vs. No)	0.036	0.269*	0.317*
	(0.183)	(0.139)	(0.177)
Panel E: Riverbeds or riverbanks			
ATE (Yes vs. No)	0.686***	0.481**	0.524**
	(0.221)	(0.219)	(0.266)
ATT (Yes vs. No)	0.308*	0.365**	0.158
	(0.180)	(0.171)	(0.212)
Panel F: Lifting water from dam, canal, river or lake			
ATE (Yes vs. No)	2.791***	0.627***	-
	(0.662)	(0.242)	
ATT (Yes vs. No)	0.140	0.183	-
	(0.252)	(0.208)	
Panel G: Overhead irrigation			
ATE (Yes vs. No)	0.157	-0.847**	-
	(0.320)	(0.382)	
ATT (Yes vs. No)	-0.149	-0.336**	-
	(0.245)	(0.167)	

Panel H: Other types of irrigation			
ATE (Yes vs. No)	-0.167	0.226	0.868**
	(0.284)	(0.173)	(0.401)
ATT (Yes vs. No)	-0.178	0.170	0.269
	(0.181)	(0.166)	(0.205)
Observations	*539*	*530*	*465*
District dummy	*Yes*	*Yes*	*Yes*
Survey round dummies	*Yes*	*Yes*	Yes

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Missing results for WHZ means the models could not converge. Models for irrigated fields in the community, cultivate on low-lying, swamp/marshland, planting on riverbeds/riverbanks, other types of irrigated agriculture and drawing water from dam, canal, river or lake, are based on the same controls as in Table 5. Including all controls for overhead irrigation leads to the models not converging. Therefore, the models include all other variables except the baseline controls.

5. Pathways, Other Outcomes and Robustness Checks

5.1 Effects on income, health care financing and environmental quality

In this section, we further investigate the possible mechanisms through which irrigated agriculture can affect child nutrition. One of the primary pathways that irrigation can have an impact on child nutrition is through the availability of diverse foods, which is closely related to nutritional outcomes. Available data, however, do not allow us to investigate this channel in detail. Table 7 reports other possible mechanisms (proxies of income and environmental quality) through which irrigation could affect nutrition outcomes. Most of the estimated coefficients of the ATT indicate a positive association, but none of them is statistically significant except improved drinking water source. The negative effect on bed net per capita raises a vital policy question on why irrigating households do not invest in preventive health care. This requires further analyses on the productive expenditure of irrigated agriculture households. In another study, Okyere and Ahene-Codjoe (2021) showed that irrigated agriculture improves household income[5], non-food consumption, and in-transfers and out-transfers (i.e., remittances) in southern Ghana. This result partly confirms the income pathway of irrigated agriculture on child nutrition outcomes in southern Ghana.

Table 7: Effects on monthly income, health care financing, and environmental quality

	(1)	(2)	(3)	(4)	(5)	(6)
Irrigated agriculture	**HH monthly income is high (>GHC400)**	**Child ever had NHIS card**	**Bed net per capita**	**Improved drinking water**	**Treat water**	**Improved sanitation**
ATE (Yes vs. No)	0.037	-0.019	-0.033***	0.021	-0.007	0.037
	(0.029)	(0.031)	(0.013)	(0.030)	(0.023)	(0.033)
ATT (Yes vs. No)	0.034	0.016	-0.021	0.057*	-0.000	-0.010
	(0.034)	(0.033)	(0.015)	(0.033)	(0.030)	(0.037)
Observations	1,264	1,232	1,090	1,257	1,231	1,245
District dummy	Yes	Yes	Yes	Yes	Yes	Yes
Survey round dummies	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Refer to Table 5 for additional information on controls included in the models; NHIS

5.2 Other outcomes

We estimated the impacts of irrigated agriculture on child illness, diarrhoea, and fever. As shown in Table 8, children in irrigating households were more likely to experience general illness or fever in the four weeks preceding the surveys (columns 1 and 3, Table 8). Although irrigated agriculture can improve child nutrition through household income and food availability, irrigation water may exacerbate the prevalence of water-related diseases in the community. Furthermore, the results on self-reported fever are inconsistent with the "paddy paradox"[6], and this shows that the estimated results on nutrition are lower bound. Irrigation systems, for example, can serve as a breeding ground for mosquitoes, leading to a higher incidence of malaria (Asayehegn, 2012; Asenso-Okyere et al., 2012).

Table 8: Effects on diarrhoea and self-reported fever in the past four weeks before the survey

	(1)	(2)	(3)
Irrigated agriculture	**Illness/injury: Yes = 1**	**Diarrhoea: Yes = 1**	**Fever: Yes = 1**
ATE (Yes vs. No)	0.033	-0.001	0.061**
	(0.031)	(0.018)	(0.027)
ATT (Yes vs. No)	0.054*	-0.017	0.066**
	(0.033)	(0.018)	(0.028)
Observations	1,240	1,240	1,240
District dummy	Yes	Yes	Yes
Survey round dummies	Yes	Yes	Yes

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Refer to Table 5 for additional information on controls included in the models.

5.3 Sensitivity analyses

The estimated parameters from the *IPWRA* estimator may suffer from omitted variable bias if unobserved time-variant characteristics are correlated with the adoption of irrigation farming and/or child nutrition outcomes. Therefore, we conducted several robustness checks using PSM, RE, FE and CRE estimators, and the results are provided in the supplementary materials (i.e., appendices). Propensity score matching was estimated using the nearest neighbour of four (NN = 4). The results are comparable across different estimation strategies (see also Appendix D). The PSM results are summarised in Appendices E, F, G, and H. Rosenbaum bounds on treatment effects estimates for the PSM results largely suggest that there is no hidden bias due to unobserved characteristics (Appendix I). However, results obtained from RE and CRE models show that irrigated agriculture improves HAZ (Appendix J1 and J2), which was not statistically significant for the *IPWRA* or PSM estimators. Similarly, results from FE estimates partly confirm those from the RE and CRE, except that the effects on WHZ were not statistically significant (Appendix J3 and J4).

We also explored the option of addressing selection bias issues using the Heckman selection model. We assumed that child health and nutrition outcome was a function of child and household characteristics and environmental quality. In contrast, the likelihood of adopting irrigated agriculture is a function of household characteristics and additional baseline information, and (indirectly) the child health and nutrition outcomes (via the inclusion of household-level characteristics, which we think determine the child health and nutrition outcomes). The estimated inverse mills ratios were not statistically significant ($p > 0.4$), suggesting that sample selection bias is less likely.

6. Conclusion and Policy Implications

Agricultural development, primarily irrigated agriculture, has the potential of reducing undernutrition in LMICs. Despite its large potential benefits, investments in agriculture are low in many sub-Saharan African countries. In this study, we examined whether households engaged in irrigated agriculture had improved child nutrition outcomes. Using a panel household survey data and a doubly robust estimator, we found that irrigated agriculture led to large improvements in child nutrition outcomes, with considerable gains for males and children under five years old. For example, a child in an irrigating household gained 0.23 units of SD in WAZ and 0.27 units of SD in WHZ during the study period. The findings on male children indicate the biases in intra-household resource allocation toward this group, which concurs with earlier findings (e.g., Pal, 1999). The estimated results are robust to alternative model specifications and estimation techniques.

Disaggregating irrigation by types, the results show that the presence of irrigated fields in the community, planting on riverbeds, and lifting water from water sources have larger impacts on child nutrition than overhead and other irrigation types. While there is broad consensus on the importance of investments in irrigation as a policy towards the reduction of undernutrition, there is still debate on the types of irrigation that could deliver these nutritional benefits. Our findings also suggest that some of the irrigation types, such as planting on riverbeds and drawing water from water sources, generate higher nutrition benefits than overhead irrigation. Moreover, the presence of irrigated fields in the community generates improved nutrition outcomes. This implies that irrigated agriculture generates community-level benefits aside from the benefits accrued to an individual or household. The results suggest that investment in low-cost SSI generates nutrition benefits in the study context.

The potential pathways that irrigation has an impact on child nutrition could be increased demand for environmental quality and healthcare financing rather than decreases in illness incidence. This is not surprising, as the results show that irrigated agriculture does not lead to investments in preventive health care (e.g., bed nets), leading to a high incidence of self-reported fever cases. Although the results are not statistically significant, the incidence of diarrhoea was consistently lower. Finally, the study identified several areas for future research on the impacts of irrigation on child nutrition outcomes. The sample for the study was relatively small, and due to the complexity of the linkages between irrigated agriculture and nutrition, future studies based on nationally representative data could shed additional light on these linkages. Furthermore, although we attempted to reduce selection problems to the extent possible using various econometric techniques, causal interpretation of the results may be biased. This is because treatment effects models and panel regressions may be unable to address all issues related to endogeneity, and therefore, the causal interpretation of empirical findings maybe be viewed with some caution. For example, unobserved child or household characteristics can still bias the true coefficient of the impacts of irrigation on child nutrition outcome. Despite these limitations, the results obtained from this study are robust to various model specifications and are relevant for policy makers and researchers on the nutrition impacts of irrigation in LMICs, including Ghana.

Notes

1 In this paper, irrigated agriculture and irrigation are used interchangeably.

2 For example, the different types of irrigation are based on different levels of water availability and management and, consequently, would lead to different levels of productivity. In this study context, we showed that different types of irrigation (overhead, water pump, etc.) lead to choices of different crops, land allocation and also income from irrigation (refer to Section 4.3).

3 Natural irrigation, including farmers cultivating on swampy areas, river beds/riverbanks, and those with access to dam or canal, whilst artificial irrigation is classified as drawing water from canals or wells, water pump, sprinkler, overhead, and any other irrigation type.

4 For example, for the average child in our data of 55 months of age, 1 standard deviation in WAZ translates to about 0.75 kg. Therefore the average child living in an irrigator household in our sample was 0.17 kg heavier than the average child living in a non-irrigator household.

5 In this study, data on income as a continuous variable exist in only in two waves instead of the four waves we relied on for this study, where income is measured as a dummy (see Okyere and Ahene-Codjoe, 2021).

6 Paddy paradox is a concept explaining low cases of malaria and other water and sanitation-related morbidities in irrigated agriculture areas (see also Ijumba and Lindsay, 2001; Ijumba et al. 2002; Asenso-Okyere et al. 2012).

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Appendix

Supplementary Materials

Appendix A: Attrition Analysis (Attrition Rate Dummy: 1 = yes, 0 = no)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Irrigated	-0.284	-0.050	-0.184	-0.047	-0.250	-0.041
	(0.270)	(0.057)	(0.170)	(0.033)	(0.169)	(0.034)
Age of child in months		-0.012***		-0.017***		-0.020***
		(0.005)		(0.004)		(0.003)
Child age squared		0.000***		0.000***		0.000***
		(0.000)		(0.000)		(0.000)
Male child		0.082**		0.021		0.028
		(0.036)		(0.033)		(0.033)
Biological child		-0.199**		-0.084		-0.072
		(0.087)		(0.059)		(0.058)
Improved drinking water		-0.110*		-0.066*		-0.058
		(0.062)		(0.039)		(0.038)
Time to drinking water source		-0.002		-0.001		-0.001
		(0.001)		(0.001)		(0.001)
Improved sanitation		0.079*		-0.005		-0.014
		(0.047)		(0.035)		(0.035)
Clean house or dwelling		0.135***		-0.099***		-0.093**
		(0.051)		(0.038)		(0.038)
Male head		0.146**		0.003		-0.013
		(0.073)		(0.060)		(0.060)
Age of head		0.002		-0.013		-0.017
		(0.011)		(0.011)		(0.010)
HH head age squared		-0.000		0.000		0.000*
		(0.000)		(0.000)		(0.000)
Reference: No formal qualification						
BECE/MSLC		-0.081		0.009		0.017
		(0.053)		(0.044)		(0.043)
SSCE and above		-0.165***		0.048		0.066
		(0.060)		(0.074)		(0.074)
Ga/Adangbe ethnic group		0.008		0.007		-0.019
		(0.052)		(0.043)		(0.043)

Electricity from national grids		-0.042		-0.041		-0.046
		(0.064)		(0.045)		(0.044)
Urban district — Yes = 1		0.071		0.109**		0.100**
		(0.048)		(0.050)		(0.050)
Household size		0.009		-0.020		-0.013
		(0.026)		(0.026)		(0.024)
Squared of household size		-0.001		0.002		0.002
		(0.001)		(0.001)		(0.001)
Internet		-0.029		0.010		0.013
		(0.068)		(0.050)		(0.050)
Number of females (>15 years)		0.003		-0.009		-0.010
		(0.025)		(0.022)		(0.022)
Married head		-0.050		0.011		0.035
		(0.061)		(0.053)		(0.053)
Head is a Christian		0.058		-0.029		0.001
		(0.043)		(0.051)		(0.050)
Road tarred at baseline		-0.097*		0.000		-0.006
		(0.052)		(0.063)		(0.062)
Presence of water bodies at baseline		-0.049		-0.095*		-0.094*
		(0.060)		(0.054)		(0.054)
Extension visit at baseline		-0.042		-0.021		-0.026
		(0.072)		(0.048)		(0.050)
Cooperative at baseline		0.107		-0.014		-0.026
		(0.090)		(0.058)		(0.058)
Market at baseline		-0.104		0.015		0.006
		(0.085)		(0.073)		(0.072)
Large livestock ownership at baseline		0.097		0.015		0.033
		(0.083)		(0.067)		(0.066)
Agricultural land ownership at baseline		0.069		-0.053		-0.053
		(0.050)		(0.049)		(0.048)
Off-farm activity at baseline		0.008		-0.013		-0.002
		(0.051)		(0.044)		(0.044)
House ownership at baseline		-0.014		0.018		0.026
		(0.053)		(0.039)		(0.040)
Constant	-1.088***	0.341	-1.329***	1.247***	-1.291***	1.344***
	(0.123)	(0.282)	(0.071)	(0.303)	(0.069)	(0.288)
Observations	318	274	1,250	1,180	1,314	1,240
R-squared	--	0.247	--	0.170	--	0.196

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

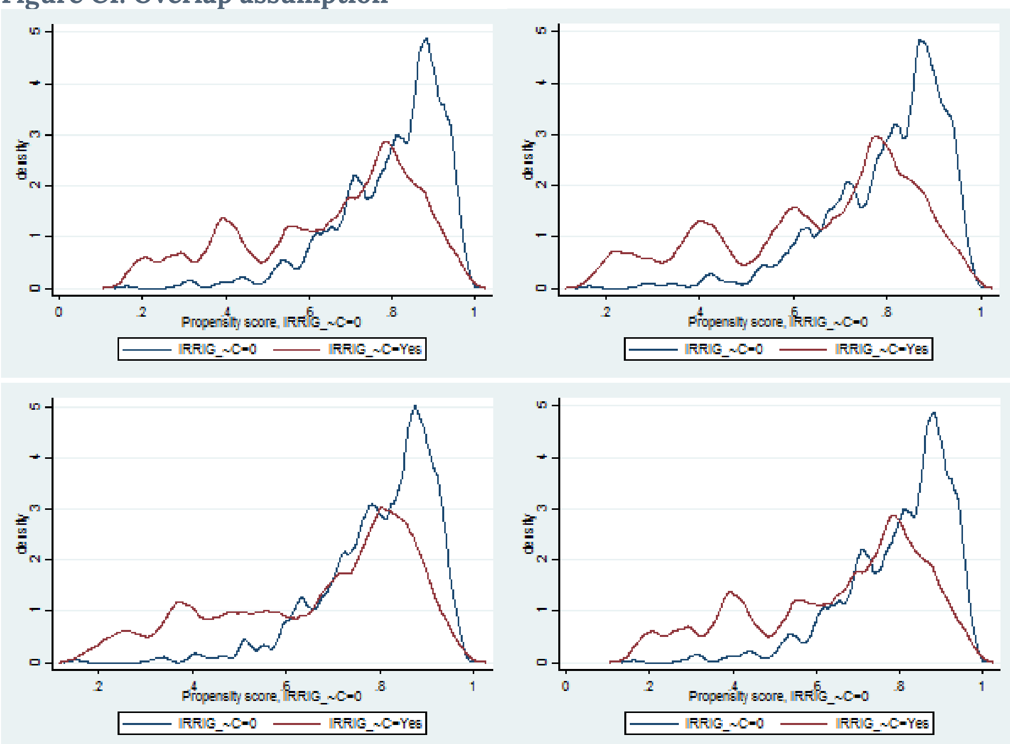
Appendix B: Summary Statistics by Survey Waves, 2014–2015

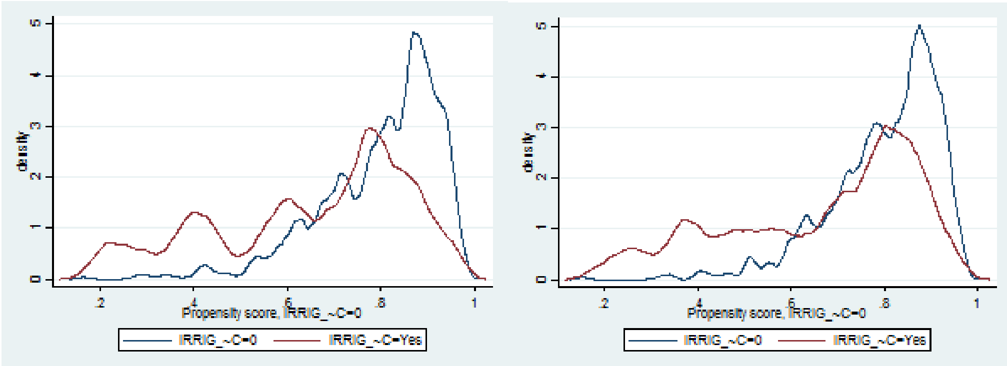
	Wave 1		Wave 2		Wave 3		Wave 4	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Irrigating HH: Yes = 1	0.296	0.457	0.269	0.444	0.181	0.386	0.198	0.399
Height-for-age z-scores	-1.191	1.403	-0.962	1.247	-0.876	1.220	-1.079	1.308
Stunted (HAZ <-2 IS THIS < -2 OR ≤ 2)	0.267	0.443	0.201	0.401	0.169	0.376	0.202	0.402
Weight-for-age z-score	-0.846	1.128	-0.844	1.147	-0.780	1.154	-0.785	1.047
Wasted (WHZ <-2)	0.050	0.218	0.085	0.280	0.061	0.240	0.078	0.269
Weight-for-height z-scores	-0.348	1.251	-0.422	1.339	-0.477	1.212	-0.237	1.335
Underweight (WAZ <-2)	0.135	0.342	0.141	0.348	0.123	0.329	0.120	0.325
Observations	318		331		392		276	

Note: Missing data will affect the descriptive statistics.

Appendix C: Diagnostics for IPWRA Models

Figure C1: Overlap assumption






```
Overidentification test for covariate balance
         H0: Covariates are balanced:

         chi2(27)     =  28.3374
         Prob > chi2  =   0.3937
```

Table C1: Covariate balance summary

	Raw	Weighted
Number of obs.	1,214	1,214.0
Treated obs.	285	619.2
Control obs.	929	594.8

VARIABLES	(1)	(2)	(3)	(4)
	Standardised differences		Variance ratio	
	Raw	Weighted	Raw	Weighted
Male head	0.215	0.061	0.698	0.887
Age of head	-0.026	-0.001	0.674	0.963
Squared of age of head	-0.061	-0.004	0.662	1.021
BECE/MSLC	-0.085	0.011	0.907	1.015
SSCE and above	0.213	0.066	1.689	1.147
Ga/Adangbe ethnic group	0.017	0.068	1.007	1.020
Electricity fron national grids	0.104	0.020	0.867	0.969
Urban district (Ga South Municipal)	-0.129	-0.015	0.975	0.995
Household size	0.035	0.059	1.293	1.032
Squared of household size	0.060	0.047	1.597	1.101
Internet	0.132	0.030	1.349	1.061
Number of females above 15 years	0.057	0.016	1.201	1.124
Married head	0.025	-0.002	0.973	1.003
Head is a Christian	0.274	0.040	0.631	0.918
Wave 2	0.129	0.014	1.147	1.013
Wave 3	-0.205	0.025	0.816	1.033
Wave 4	-0.087	-0.019	0.879	0.970
Road tarred at baseline	-0.060	0.032	0.858	1.096
Presence of water bodies at baseline	0.228	0.035	0.731	0.943

Extension visit at baseline	0.431	0.052	1.811	1.046
Cooperative at baseline	0.404	0.115	2.324	1.188
Market at baseline	0.181	0.007	1.526	1.014
Large livestock ownership at baseline	-0.142	-0.030	0.664	0.908
Agricultural land ownership at baseline	0.180	0.031	0.904	0.977
Off-farm activity at baseline	0.096	0.014	0.949	0.991
House ownership at baseline	0.115	0.012	0.929	0.990

Comparison of means and variances

VARIABLES	(1)	(2)	(3)	(4)
	Means		Variances	
	Control	Treated	Control	Treated
Male head	0.777	0.860	0.173	0.121
Age of head	46.403	46.144	122.090	82.293
Squared of age of head	2275.158	2211.260	1299591.000	860565.800
BECE/MSLC	0.265	0.228	0.195	0.177
SSCE and above	0.083	0.151	0.076	0.129
Ga/Adangbe ethnic group	0.437	0.446	0.246	0.248
Electricity fron national grids	0.764	0.807	0.180	0.156
Urban district (Ga South Municipal)	0.478	0.414	0.250	0.243
Household size	7.822	7.923	7.181	9.283
Squared of household size	68.363	72.021	2845.568	4544.387
Internet	0.107	0.151	0.095	0.129
Number of females above 15 years	2.010	2.074	1.154	1.385
Married head	0.747	0.758	0.189	0.184
Head is a Christian	0.765	0.870	0.180	0.113
Wave 2	0.241	0.298	0.183	0.210
Wave 3	0.323	0.232	0.219	0.179
Wave 4	0.217	0.182	0.170	0.150
Road tarred at baseline	0.113	0.095	0.100	0.086
Presence of water bodies at baseline	0.734	0.828	0.195	0.143
Extension visit at baseline	0.139	0.316	0.120	0.217
Cooperative at baseline	0.082	0.225	0.075	0.175
Market at baseline	0.095	0.154	0.086	0.131
Large livestock ownership at baseline	0.111	0.070	0.099	0.065
Agricultural land ownership at baseline	0.594	0.681	0.241	0.218
Off-farm activity at baseline	0.614	0.660	0.237	0.225
House ownership at baseline	0.630	0.684	0.233	0.217

Appendix D: Analysis of Treatment Effects without Controls

Table D1: Effects on child health and nutrition outcomes

Irrigated agriculture	**Height for age (1)**	**Weight for age (2)**	**Weight for height (3)**
Average treatment effect (ATE)			
Irrigated vs. non-irrigated agriculture	0.056	0.217***	0.198**
	(0.091)	(0.076)	(0.093)
Average for non-irrigated agriculture	-1.027	-0.865	-0.432
	(0.041)	(0.036)	(0.043)
Observations	**1,256**	**1,256**	**1,103**
Average treatment effect on the treated (ATET)			
Irrigated vs Non-irrigated agriculture	0.056	0.217***	0.198**
	(0.091)	(0.076)	(0.093)
Average for non-irrigated agriculture	-1.027	-0.865	-0.432
	(0.041)	(0.036)	(0.043)
Observations	**1,256**	**1,256**	**1,103**

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05. The analyses are without controls. Similar results are observed for both ATE and ATET estimations as there are no controls to correct for the treatment assignment.

Appendix E: Treatment Effects from Propensity Score Matching

	Height for age					Weight for age				
	(1) Full sample	(2) Ages 0–4	(3) Ages 5–8	(4) Males	(5) Females	(6) Full sample	(7) Ages 0–4	(8) Ages 5–8	(9) Males	(10) Females
Panel A: ATE										
Irrigated vs. Non-irrigated	0.069	0.144	-0.112	0.184	0.102	0.207**	0.226*	0.088	0.351**	0.192
	(0.114)	(0.163)	(0.188)	(0.194)	(0.146)	(0.097)	(0.134)	(0.171)	(0.142)	(0.154)
Panel B: ATT										
Irrigated vs. Non-irrigated	-0.051	-0.111	0.015	0.348*	-0.160	0.217**	0.353**	0.204	0.465***	-0.026
	(0.133)	(0.191)	(0.175)	(0.198)	(0.188)	(0.108)	(0.148)	(0.145)	(0.142)	(0.182)
observations	1,214	646	568	617	597	1,209	651	558	618	591

Appendix E: Continued

	Weight for height				
	(11)	(12)	(13)	(14)	(15)
	Full sample	Ages 0–4	Ages 5–8	Males	Females
Panel A: ATE					
Irrigated vs. non-irrigated	0.334***	0.173	0.251	0.269	0.281
	(0.114)	(0.144)	(0.196)	(0.186)	(0.181)
Panel B: ATT					
Irrigated vs. non-irrigated	0.350***	0.388**	0.263	0.272	0.182
	(0.135)	(0.172)	(0.218)	(0.179)	(0.203)
Observations	*1,044*	*617*	*427*	*532*	512

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included in the models are the same as those used in outcome models in Table 5.

Appendix F: Differential Effects of Irrigated Agriculture on Child Nutrition Outcomes

	(1)	(2)	(3)
Types of irrigation	Height for age	Weight for age	Weight for height
Panel A: Natural irrigation			
ATE (Yes vs. No)	0.279+	0.317**	0.103
	(.179)	(0.143)	(0.182)
ATT (Yes vs. No)	0.071	0.249*	0.148
	(0.172)	(0.132)	(0.184)
Panel B: Artificial irrigation			
ATE (Yes vs. No)	0.200	0.303*	0.040
	(0.203)	(0.162)	(0.218)
ATT (Yes vs. No)	0.036	0.250*	0.102
	(0.176)	(0.141)	(0.197)
Panel C: Irrigated fields in the community			
ATE (Yes vs. No)	0.002	0.353***	0.537***
	(0.162)	(0.137)	(0.182)
ATT (Yes vs. No)	0.058	0.482***	0.629***
	(0.199)	(0.174)	(0.227)
Panel D: Cultivate on low-lying, swamp/marshland			
ATE (Yes vs. No)	0.047	0.247	0.094
	(0.220)	(0.176)	(0.224)
ATT (Yes vs. No)	0.012	0.236+	0.338
	(0.195)	(0.144)	(0.207)
Panel E: Riverbeds or riverbanks			
ATE (Yes vs. No)	0.362	0.659***	0.316
	(0.253)	(0.221)	(0.302)

ATT (Yes vs. No)	0.327*	0.416**	0.337
	(0.194)	(0.167)	(0.229)
Panel F: Lifting water from dam, canal, river or lake			
ATE (Yes vs. No)	0.762**	0.357	0.184
	(0.336)	(0.252)	(0.378)
ATT (Yes vs. No)	0.473*	0.373**	0.206
	(0.268)	(0.189)	(0.272)
Panel G: Overhead irrigation			
ATE (Yes vs. No)	-0.319	-0.234	-0.329
	(0.314)	(0.272)	(0.357)
ATT (Yes vs. No)	-0.235	-0.036	-0.253
	(0.264)	(0.225)	(0.270)
Panel H: Other types of irrigation			
ATE (Yes vs. No)	-0.163	-0.289	0.420
	(0.319)	(0.307)	(0.290)
ATT (Yes vs. No)	-0.060	0.163	0.248
	(0.209)	(0.177)	(0.220)
Observations	*539*	*530*	*465*

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included in the models are the same as those used in outcome models in Table 5.

Appendix G: Effects on Monthly Income, Healthcare Financing, and Environmental Quality

	(1)	(2)	(3)	(4)	(5)	(6)
	HH monthly income is high (>GHC400)	Child ever had NHIS card	Bed net per capita	Improved drinking water	Treat water	Improved sanitation
ATE (Yes vs. No)	0.050	-0.017	-0.033*	0.035	-0.030	0.021
	(0.041)	(0.042)	(0.018)	(0.039)	(0.032)	(0.042)
ATT (Yes vs. No)	0.083*	-0.015	-0.032*	0.064	-0.031	-0.030
	(0.044)	(0.047)	(0.019)	(0.042)	(0.039)	(0.047)
Observations	1,264	1,232	1,090	1,257	1,231	1,245

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included in the models are the same as those used in outcome models in Table 5.

Appendix H: Effects on Diarrhoea and Self-reported Fever in the Last Four Weeks

	(1)	(2)	(3)
	Illness/injury: Yes = 1	Diarrhoea: Yes = 1	Fever: Yes = 1
ATE (Yes vs. No)	0.014	-0.030*	0.069**
	(0.037)	(0.018)	(0.031)
ATT (Yes vs. No)	0.063	-0.016	0.095
	(0.043)	(0.021)	(0.035)
Observations	1,240	1,240	1,240

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included in the models are the same as those used in outcome models in Table 5.

Appendix I: Rosenbaum Bounds on Treatment Effects Estimates for the PSM

Outcome variables	Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
Height-for-age z-scores	1	0.000	0.000	-1.007	-1.007	-1.076	-0.939
	2	0.000	0.000	-1.385	-0.642	-1.462	-0.570
	3	0.000	0.000	-1.608	-0.435	-1.691	-0.360
Weight-for-age z-scores	1	0.000	0.000	-0.826	-0.826	-0.883	-0.769
	2	0.000	0.000	-1.136	-0.515	-1.198	-0.453
	3	0.000	1.1e-16	-1.315	-0.336	-1.381	-0.270
Weight-for-height z-score	1	0.000	0.000	-0.425	-0.425	-0.491	-0.357
	2	0.000	0.023	-0.759	-0.078	-0.829	-0.002
	3	0.000	1.000	-0.948	0.130	-1.024	0.216

Notes: N= 1259 matched pairs; Gamma is the log odds differential assignment due to unobserved factors; sig+ indicates upper bound significance level; sig- represents lower bound significance level; t-hat+ is the upper bound Hodges-Lehmann point estimate; t-hat- is the lower bound Hodges-Lehmann point estimate; CI+ represents upper bound confidence interval (a = 0.95); CI- indicates lower bound confidence interval (a = 0.95).

Appendix J: Panel Regression Analyses

Table J1: Random effects estimates

	(1)	(2)	(3)
Variables	Height-for-age z-scores	Weight-for-age z-scores	Weight-for-height z-scores
Irrigated agriculture – yes=1	0.136*	0.220***	0.198**
	(0.080)	(0.072)	0.101
Constant	-2.684***	-0.965	0.529
	(0.989)	(0.837)	(0.830)
Wave fixed effect	Yes	Yes	Yes
District fixed effect	Yes	Yes	Yes
Controls as in PSM estimates	Yes	Yes	Yes
Observations (children-wave)	1,214	1,209	1,044

Number of children	476	483	434
R-squared (overall)	0.116	0.043	0.083
Prob > Chi^2	0.000	0.018	0.000

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Standard errors were adjusted for 284 households.

Table J2: Correlated random effects estimates

Variables	(1) Height for age	(2) Weight for age	(3) Weight for height
Irrigated agriculture	0.127*	0.214***	0.209**
	(0.069)	(0.070)	(0.093)
Constant	-4.290***	-1.789**	0.752
	(0.912)	(0.793)	(0.925)
Wave dummies	Yes	Yes	Yes
District dummy	Yes	Yes	Yes
Controls as in PSM estimates	Yes	Yes	Yes
CRE controls	Yes	Yes	Yes
Observations (children-wave)	1,214	1,209	1,044
Number of children	476	483	434
R-squared (overall)	0.129	0.055	0.0852
Prob > chi^2	0.000	0.000	0.001

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; same controls as the PSM estimates in Appendix A; CRE controls include means of time-varying explanatory variables such as child age and its squared term, age of HH head and its squared term, household size and its squared term.

Table J3: Child fixed effects estimates

Variables	(1) Height for age	(2) Weight for age	(3) Weight for height
Irrigated agriculture	0.143*	0.197**	0.120
	(0.076)	(0.078)	(0.113)
Constant	3.103	5.887***	3.720
	(2.238)	(2.294)	(3.196)
Wave dummies	Yes	Yes	Yes
Time invariant variables excluded	Yes	Yes	Yes
Observations (children-wave)	1,214	1,209	1,044
Number of children	476	483	434
R-squared (overall)	0.033	0.009	0.008
Prob > chi^2	0.000	0.000	0.006

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table J4: Household fixed effects estimates

Variables	(1) Height for age	(2) Weight for age	(3) Weight for height
Irrigated agriculture	0.183*	0.232**	0.138
	(0.105)	(0.097)	(0.124)
Constant	1.101	2.727	-0.276
	(3.360)	(3.193)	(3.979)
Wave dummies	Yes	Yes	Yes
Time invariant variables excluded	Yes	Yes	Yes
Households dummies	Yes	Yes	Yes
Observations (children-wave)	1,214	1,209	1,044
R-squared	0.633	0.582	0.574
Prob > chi^2	0.000	0.000	0.000

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

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