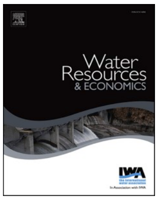
Water Resources and Economics 33 (2021) 100174

Contents lists available at ScienceDirect

Water Resources and Economics

journal homepage: http://www.elsevier.com/locate/wre



The impact of irrigated agriculture on child nutrition outcomes in southern Ghana

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ARTICLE INFO

Keywords:
Irrigated agriculture
Child nutrition
Intrahousehold allocation
Treatment effect estimators
Panel regressions

ABSTRACT

In this study, we investigated whether irrigated agriculture results in improved child nutrition outcomes among farm households in southern Ghana. Using panel data collected between 2014 and 2015, this study seeks to add to the growing body of literature on the determinants of irrigated agriculture adoption, its effects on child nutrition, and the potential pathways through which irrigation can affect child nutrition outcomes. The results from the inverse probability weighted regression adjustment (IPWRA) estimator suggest that children living in irrigating households have, on average, 0.23 standard deviations of weight-for-age and 0.27 standard deviations of weight-for-height higher than their counterparts; with males and under-five children gaining substantial improvements. Disaggregating irrigation by types, the results indicate that households planting on riverbeds or riverbanks had improved child nutrition. In contrast, children living with households lifting water from water sources had 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.

1. Introduction

In many low- and middle-income countries (LMICs), reducing undernutrition remains a primary public health goal, and this is more evident in the Sustainable Development Goals (SDGs), where 12 of the 17 (about 70%) goals are related to nutrition [42]. Globally, undernutrition accounts for about 45% of deaths of under-five children [13]. Despite several nutrition-sensitive interventions, undernutrition remains disproportionately higher in LMICs. The health effects of child undernutrition are often irreversible with long-term consequences. Many empirical studies show that undernutrition can impair cognitive and physical development, school performance, and labor productivity in the later years of their life (e.g., Refs. [5,24]. In Ghana, about 19% of under-five children are stunted (low height-for-age z-scores), and 11% of children are underweight (low weight-for-age z-scores) [23]. The prevalence of child undernutrition is even much higher in rural areas than in urban areas.

Investments in agriculture are essential to enhance food and nutrition security. Agriculture employs about 38% of the labor force despite Ghana's population increasingly urbanized, and the gross domestic product (GDP) shares of the agriculture sector sharply

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https://doi.org/10.1016/j.wre.2020.100174
Received 17 June 2020; Received in revised form 13 December 2020; Accepted 17 December 2020

declined over the last decade [61]. Public investments can improve agricultural yield and productivity through knowledge transfer and infrastructure expansion [16]. In Africa, expanding irrigation technology is one of the agrarian policy goals, and this is emphasized in the recent 2018 Malabo-Montpellier Panel report. However, public investments in agriculture remain low in many African countries. In Ghana, for instance, public agricultural expenditure (% GDP) averaged about 3.3% from 2001 to 2015, significantly less than the 10% target of the Comprehensive Africa Agricultural Development Programme (CAADP) commitment [9].

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 the dependence of rain-fed agriculture by making crop production possible in marginal lands where rainfall is inadequate [29]. Irrigation also increases land productivity using an appropriate input mix, thereby generating higher farm incomes. Along with that, small-scale irrigation (SSI) using tubewell in Nigeria increased per hectare returns from 65 to 500% [14], while, treadle pump irrigation increased income per hectare by over 500% in Malawi [32]. In Balana et al. [8], 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-can generates higher returns per capital investment, indicating potential differential impacts of irrigation technologies. Altogether, recent evidence suggests that SSI schemes generate the highest economic pay-offs and are more sustainable [57,58]. The main objective of this study is to examine the impact of irrigation 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. [4] reported that households with irrigation increase yield and consumption of fruits and vegetables, spend more on food and health care services than households without irrigation. 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 [10,11,41]. Although investment in irrigation is supported to ensure food and livelihood security (e.g. Ref. [18], 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 instance, homestead irrigation typically owned by women is used to grow vegetables for their own consumption and/or for local markets. On the other hand, in large scale irrigation schemes, farmers produce mainly cash crops in which the women often do not have much control over the income.

Studies assessing the impact of irrigated agriculture on child nutrition using anthropometric measurements are few (e.g., Refs. [10,48]. 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 looked into the gender-differentiated impact of irrigated agriculture on child nutrition outcomes. There is a need to build a strong evidence base for policymakers and development practitioners to guide how to design successful programs and facilitate the adoption of irrigation technologies. This study attempts to fill these gaps.

With the growing interest in expanding SSI in Ghana, this is an important and policy-relevant topic. In addition, the implementation challenges encountered with the so-called "*One Village: One Dam*" program, 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 program 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 the flagship program of "*One Village: One Dam*" and the reported complaints of the quality of completed dams [21]. For policy decisions, it is also essential to identify the types of irrigation technologies that are nutrition-sensitive and hasten the implementation of the program.

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. Refs. [34,41], mostly rely on food consumption diversity. Second, the current study uses panel data allowing to control for time dimension in the analysis. Other studies (e.g. Refs. [10,20,27,48], have relied on cross-sectional data affected by endogeneity issues. Third, and most importantly, 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 are that children living with irrigating households have, on average, higher weight-for-age and weight-for-height than children residing with non-irrigating households. The results are robust to various model specifications and alternative estimation approaches.

2. Background

2.1. Irrigated agriculture in Ghana

In Ghana, expanding irrigated agriculture has been one of the underlying pillars of modernizing agriculture in the country's agricultural policies. Nevertheless, empirical studies on the impact of irrigated agriculture on child nutritional outcomes are scarce in Ghana. Agriculture is important because it is a source of food and income for the vast majority of rural households although it is mainly subsistent and rain-fed. This implies that seasons of low rainfall lead to low yields, which can affect poor rural households' livelihoods. As part of food security and poverty reduction strategies, the government of Ghana has designed policies and programs to expand SSI in many rural communities. Small-scale irrigation can promote all-year-round food production and increase yields through reliance on water resources for agricultural purposes. With irrigated agriculture, the types of crops farmers grow will also change, which has indirect implications on the types of food supply and consumption in the communities.

In Ghana, agricultural policies primarily focused on modernizing the sector through intensification, improved agronomic practices, irrigation, and mechanization. Available statistics from the Ministry of Food and Agriculture (MoFA) [36] indicate that, in 2016, the share of agricultural land to the total land area of Ghana is 57%, of which 46.6% of agricultural land was under cultivation, with only 3.6% of the total cultivated area is under irrigation due to the lack of public investment [36]. Since the potentials of scaling up irrigated agriculture to increase yield and productivity, the government has a great interest in investing in irrigation infrastructure. As an example, in 2017, the government initiated the "*One Village: One Dam*" program in Northern Ghana to construct small-scale dams.

2.2. The impact of irrigated agriculture on nutrition and health outcomes

Irrigation can affect health and nutrition outcomes through various pathways (see Fig. 1). Poorly designed irrigation, for instance, can bring adverse impacts on the environment and human health through increased water-related diseases and drinking water contaminations. Irrigation systems increase the availability of water for domestic purposes where multiple-use water systems are common; however, it can be a source of domestic water contamination [20,47,50]. Moreover, it can exacerbate the incidence of waterborne diseases by creating favorable conditions for disease-vectors such as mosquitoes [6,7]. On the one hand, irrigated agriculture could increase productivity, production diversity, and food availability, which in turn improve household income and consumption (e.g., Refs. [3,25,38,41,54]. Relatedly, the increased income associated with irrigation enables households to access improved health care services, which can enhance the health and nutrition outcomes of household members.

Irrigation water serves as source of drinking water in many rural communities where access to improved drinking water sources is inadequate [49,53]. Increasing water availability for domestic purposes helps households to meet basic hygiene practices that improve health associated with water quantity [53]. In a related manner, increasing water availability reduces the burden of water collection time, which is often disproportionately borne by women and girls. The time saving from water collection can be used for other income-generating activities, such as agricultural production, social events, and childcaring [43], with direct and indirect health consequences. A recent review has synthesized the available evidence on the impacts of irrigation on health and nutrition in sub-Saharan Africa (see Ref. [17]; for a detailed review).

3. Methods

3.1. Data

This study relies 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 (see Ref. [39], for detailed information). Informed consent was obtained for participant households of the study. The survey instruments for the baseline survey 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, health care expenses, household consumption expenditures, and other socioeconomic characteristics. This survey instrument was repeated for the end line 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

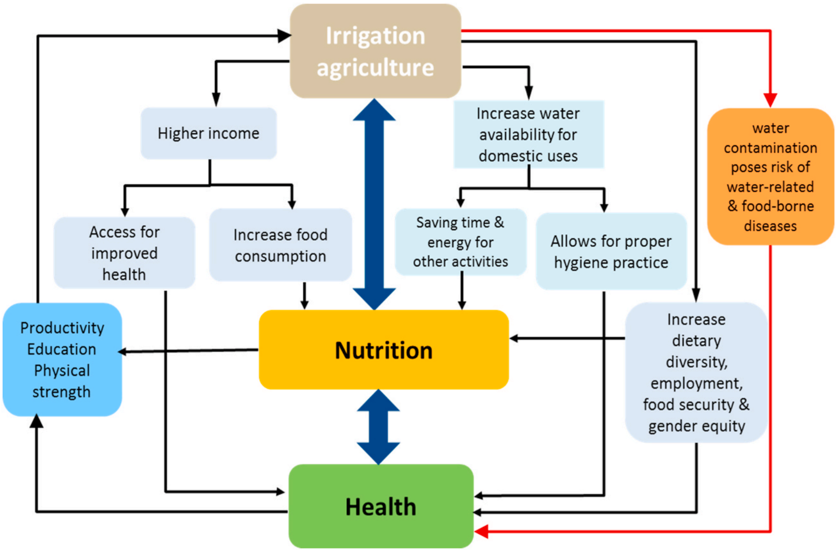

Fig. 1. Linkage between irrigated agriculture and health and nutrition
Source: Usman [51].

anthropometric measures, information on income, health care 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 socioeconomic characteristics presents the opportunity to examine the potential mechanisms. According to Kirk et al. [26], the short time 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 is on children living in agricultural households, but children from non-agricultural households are maintained due to the relatively smaller sample size. We restrict the analysis on children with anthropometric measures in the baseline survey or born after the baseline survey (see Ref. [28]. The final analysis consists of 1317 child observations across the four survey waves: 318, 331, 392, and 276 child observations in the surveys of 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 waves were observed. Fig. 2 depicts a map of the study areas. Finally, the sample is 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 generalized to the whole population. While we acknowledge that the sample size may be small, there are no alternative panel datasets for Ghana (based on our knowledge) containing anthropometrics with representative sample for children in both irrigated and non-irrigated agricultural 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 merely 3% of the sampled households declared to irrigate their land [46]. Similarly, in Ghana, various types of irrigation technologies exist but less than 2% of arable lands are under irrigation [35]. 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 [2].

This paper uses unbalanced panel data, with some of the children not measured in all the survey rounds. Accordingly, the study may suffer from attrition bias. Although we control for survey round fixed effects in our analyses, the attrition rate, if systematic and affects one group more than the other, could lead to potential upward estimation bias. We undertake an analysis of the attrition rate, and we

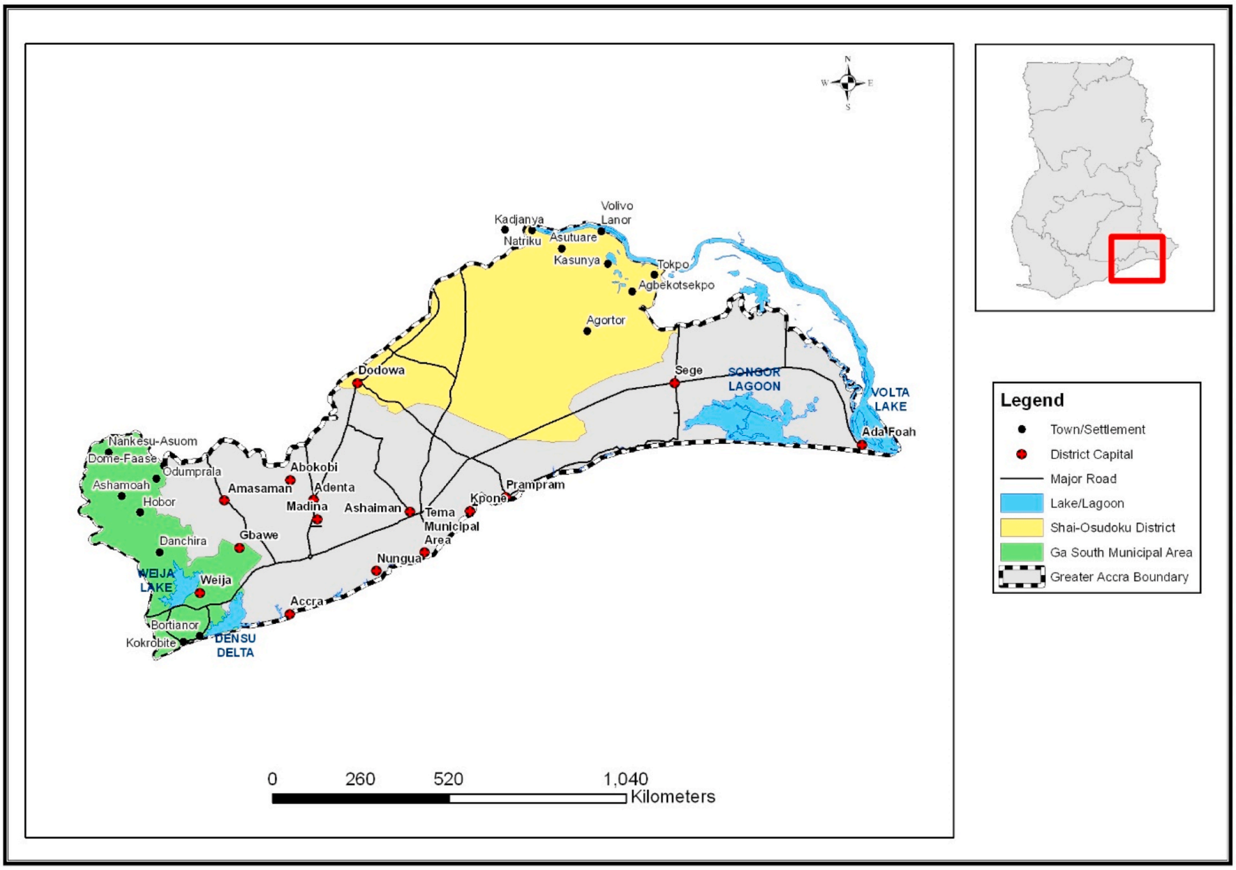

Fig. 2. Map of the study areas.
Source: Okyere [39].

find that it is similar for both irrigators and non-irrigators (Appendix G). For instance, we analyzed 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. [26]. We find that the attrition rate is unaffected by the adoption of irrigated agriculture. Furthermore, the results do not change by defining attrition either to mean children with one or two observations and older than 12 months of age in the baseline data or to mean children with only one or two 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) are used as indicators of child nutrition. The use of anthropometrics, which is recommended by WHO for child nutrition measures, is few 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, calorie intakes, which are mainly based on recall by the respondent and prone to recall bias. The study is based on a random utility framework where a household adopted irrigation technologies to maximize its utility (i.e., child nutrition) by comparing it to the utility from non-irrigating households. Further, closely following Grossman [22] and Mangyo [33], this study conceptualizes 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 is specified in its basic form as:

$$N_{ijt} = \propto + \varnothing IA_{jt} + \rho H_{jt} + \mu C_{ijt} + \omega V_{ijt} + W_t + D_c + \varepsilon_{ijt} \tag{1}$$

where i represents child, t indicates survey waves ($t \in 0, 1, 2, 3$), j indicates household, IA a dummy variable indicating whether household participation in irrigated agriculture, N represents child nutritional outcomes, 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, while ε represents the error term, $\propto$, $\varnothing$, 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 instance, if resource endowed farmers are more likely to participate in irrigated agriculture, impact assessments that fail to account for such household's characteristics adequately will lead to biased estimates (see Ref. [16]; for discussion on impact evaluation of infrastructures). Furthermore, under-nutrition is caused by several factors, including the environment. Prior 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

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	1317
HH participates in irrigated agriculture – Yes = 1	0.234	0.423	1314
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
Lifting 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
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 (GHS)	1397.77	1384.40	72
Source of labor for irrigated agriculture			
Hired labor	0.176	0.383	74
Family labor	0.527	0.503	74
Both family & hired labor	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.

[a] Percentage of cases reported because of multiple responses.

practices (e.g., Refs. [55,60]. All of these factors could affect the validity of the estimated impact, notably if these factors are correlated with irrigated agriculture.

This study focuses 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, employed 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 [56]. 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 [15,31]. However, one of the main limitations of the 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 are fitted using a logit model to generate the expected outcomes of the probabilities of participation and non-participation in irrigated agriculture. The independent variables are 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 Refs. [31,44]. The study relies 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 analyzes both the average treatment effect (ATE) and average treatment effects on the treated (ATT). The ATT can be obtained with the following mathematical representation:

$$\begin{aligned} ATT^{IA_p|IA_0} &= E\left\{N^{IA_p} - N^{IA_o} \middle| T = IA_p\right\} \\ &= E\left\{N^{IA_p} \middle| T = IA_P\right\} - E\left\{N^{IA_0} \middle| T = IA_0\right\},\ T \in \{0,\ 1\} \end{aligned} \tag{2}$$

where $E\{\}$ is the expectation operator, IA_p indicates the adoption of irrigated agriculture and IA_0 denotes non-irrigated agriculture, N^{IA_p} and N^{IA_o} represent the nutritional outcomes of a child for irrigating and non-irrigating households, respectively, and T is a dummy variable indicating whether 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 later presented in this section. We find that agriculture is the main livelihood activity in the study area, and less than one-fourth of the households engaged in irrigated agriculture. The most commonly practiced (22.3%) irrigation technology is access to water from various water sources, followed by cultivating on low-lying, swamp or marshland (19.2%), other types of irrigation including drip irrigation, surface irrigation, among others (13.6%). Around 6.3% of the households apply overhead irrigation using a watering can or bucket. Sprinkler irrigation (3.3%) is less widespread in the study area. On average, families spend about three and a half days each week on irrigated fields. The average irrigable farm size is 1.3 ha, and the average income from irrigated agriculture is about GHS 1398 (equivalent to USD 466). Over half of the sampled households entirely depend on family labor for irrigated agriculture. Irrigating household members experienced health problems, such as body pains (86.1%), injury (48.1%), malaria (38%), and respiratory diseases (25.3%) in the preceding four-weeks before the survey.

Reported in Table 2 are child nutritional outcomes by irrigation status, and the results show that irrigating households have better child nutrition than non-irrigating households (column 3). Except for HAZ, there are statistically significant mean differences in children's WAZ and WHZ 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 F.

Based on previous empirical studies (e.g. Ref. [1], we have 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 is male-headed with low educational qualification (65.3% with

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 (1.405)	−1.027 (1.260)	0.056 (0.086)
Weight-for-age z-scores	−0.649 (1.147)	−0.865 (1.113)	0.217*** (0.075)
Weight-for-height z-score	−0.234 (1.316)	−0.432 (1.267)	0.198** (0.092)
Observations	308	1006	

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

Table 3
Summary statistics.

Variable	Full sample	Irrigated agriculture	Non-irrigated agriculture	Mean difference
	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 SSCE 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 bednets 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 (>GHS 400)	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 debt	0.21 (0.41)	0.18 (0.38)	0.22 (0.42)	−0.04
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 diarrhea 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	1006	

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

[a] Use of public dump/garbage center or collection by a local authority/a private firm. Statistical significance denoted at: ***p < 0.01, **p < 0.05, *p < 0.1.

no formal education). Access to the internet is deficient (11.6%), but access to environmental quality indicators are moderately high. According to the WHO's Joint Monitoring Program (JMP) classifications, about 68% of the households have access to improved water supply, while 44% have access to improved sanitation. Around one-fifth of the households treat water to make it safer for consumption. Further, most households are living in communities having water bodies. Half of the children are males and biological children of household heads (75%). The self-reported prevalence of diarrhea among children is low, while fever is relatively high (15.4%). Additionally, Table 3 provides summary statistics by irrigation status. The results suggest that irrigated households are relatively male-headed and educated, have significantly better access to the internet and improved drinking water, high monthly income, more extension visits, high presence of cooperative or farmer group organizations, and owned more agricultural land. On the other hand, non-irrigated households owned more large livestock than irrigated households. On children's characteristics, both groups are comparable in terms of age, gender, and relationship to household head; except for health care financing and malaria prevalence. Lastly, imbalances in summary statistics for observational studies are common in the empirical literature. In Zeweld et al. [59], for example, seven out of the 11 variables were statistically different at the conventional significance level. Similarly, in Pasarelli et al. [41] 13 out of 21 (for Ethiopia data) and 17 out of 21 variables (for Tanzania data) were statistically different from each other.

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

Table 4
Estimates for factors influencing participation in irrigation.

VARIABLES	Pooled Logit	RE Logit	RE Logit	CRE Logit	CRE Logit
	(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 SSCE 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 ($\geq$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)	1293	1293	1293	1293	1293
Number of children	–	507	507	507	507
Prob $>$ Chi^2	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.

the data but without including unobserved heterogeneity). The last two columns (4 & 5) summarize the estimates of CRE models, which consider both the panel nature of the data and unobserved heterogeneity [30,37,45]. 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 cooperative in the community are more likely to increase household adoption of irrigated agriculture (column 4 of Table 4). These results partly confirm previous studies (e.g. Ref. [1], 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 to adopt irrigation technology. Ownership of farmland, presence of water resources, and religion of household head being Christian are also positively associated with irrigation adoption. On the other hand, ownership of livestock is negatively and significantly associated with irrigation adoption. Regression results in the other columns show the importance of different institutional and socioeconomic characteristics in influencing the decision of households to undertake irrigated agriculture.

4.2.2. *Effects on nutrition outcomes*

The effect of irrigated agriculture on child nutrition outcomes is summarized 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 find the model specifications can balance the covariates and samples in the data. As the estimated density of the predicted probabilities displays in Appendix H1, 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 instance, 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 ratio for all the variables are close to one while the standardized difference is close to zero (Appendix H2). Therefore, the results show that once we control for covariates/propensity score, the probability of treatment is random among irrigators and non-irrigators 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 [31,44,59], 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 instance, the weight of children living in irrigating households are, on average, 0.23 units of SD higher compared to children living with non-irrigating households, and this effect is even larger for male children (column 4, Panel B of Table 5). When disaggregating the sample by age groups, the estimated effect of irrigated agriculture is still large and positive and statistically significant at the conventional significance levels. The results further reveal that the WHZ of children of irrigating households is, on average, 0.27 units of SD more than children of non-irrigating households. The differential impact of irrigated agriculture on WHZ is 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	**1214**	**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 & its squared term, head's level of education, religion, marital status, ethnicity, HH has electricity from the national grid, urban district, HH size & its squared term, the number of female HH member $\geq$15 years & 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 & survey fixed effects. The outcome model is specified using all the variables included in the treatment model in addition to child characteristics & other environmental variables. Child-specific characteristics include the age of a child in months & its squared, gender, the child being biological offspring of the HH head. The environmental variables include HH use of improved drinking water & improved sanitation, the surroundings were observed to be clean/average by data enumerator, & 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 examine whether different types of irrigations have different impacts on child nutritional outcomes. To test that, we estimated the same outcome variables based on irrigation types, and the results are summarized in Table 6. The estimation strategy compares the various types of irrigation to those not using that specific type of irrigation. The analyses assume that the different irrigation types are mutually exclusive, although, in reality, farmers adopt multiple irrigation options, particularly on those involving low technology options. We do this mainly for practical and methodological reasons. The technologies involved are many and the data is too small to allow us to undertake complex analysis of the combination of the irrigation options (see Ref. [12] for analyses of combining agricultural technologies). Unfortunately, we do not have additional irrigation type-specific information that could be used to address the above shortcomings. Moreover, some of the irrigation types rely on similar technologies, and including dummies of these other types will 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 employed is relevant as it presents evidence of the differential impacts of irrigated agriculture on child nutrition outcomes.

Our findings suggest that having irrigated-fields in the community is positively and significantly associated with all child nutritional indicators except for HAZ. For instance, the ATT estimates suggest that the WAZ of children with irrigated fields in the community are 0.34 units of SD higher than their counterparts. This partly confirms previous studies on the local economy or distributional effects of irrigation [19,52]. Similarly, households cultivating on low-lying, swamp/marshland show 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 are generally robust. Although the estimated ATT for irrigation type of lifting water from dams/canals/rivers/lakes are positive across for the different nutritional indicators, the coefficients are statistically nonsignificant (Panel D of Table 6). Note that the ATE estimate is enormous and estimated imprecisely which might be due to the small number of samples in this group. For instance, about 8% of the samples fall in this group and a higher height-for-age compared to 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 do not have a significant impact on HAZ (long-term nutritional indicators). In contrast, the riverbeds/riverbanks irrigation type does not have a considerable effect on WHZ (Table 6).

An essential policy question is why should different types of irrigated agriculture lead to differential impacts on nutrition? The plausible explanation is that in this study context, similar to previous studies (e.g. Refs. [8,41,59], different types of irrigated agriculture are involved with different technologies with 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 to 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 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

Table 6
Differential effects of irrigated agriculture on child nutrition.

Types of Irrigated Agriculture	(1) HAZ	(2) WAZ	(3) WHZ
Panel A: Irrigated fields in the community			
ATE (Yes vs. No)	−0.091 (0.127)	0.192* (0.105)	0.489*** (0.155)
ATT (Yes vs. No)	0.019 (0.136)	0.343*** (0.130)	0.648*** (0.198)
Panel B: Cultivate on low-lying, swamp/marshland			
ATE (Yes vs. No)	0.303** (0.153)	0.334*** (0.121)	−0.100 (0.148)
ATT (Yes vs. No)	0.036 (0.183)	0.269* (0.139)	0.317* (0.177)
Panel C: Riverbeds or riverbanks			
ATE (Yes vs. No)	0.686*** (0.221)	0.481** (0.219)	0.524** (0.266)
ATT (Yes vs. No)	0.308* (0.180)	0.365** (0.171)	0.158 (0.212)
Panel D: Lifting water from dam, canal, river or lake			
ATE (Yes vs. No)	2.791*** (0.662)	0.627*** (0.242)	–
ATT (Yes vs. No)	0.140 (0.252)	0.183 (0.208)	–
Panel E: Overhead irrigation			
ATE (Yes vs. No)	0.157 (0.320)	−0.847** (0.382)	–
ATT (Yes vs. No)	−0.149 (0.245)	−0.336** (0.167)	–
Panel F: Other types of irrigation			
ATE (Yes vs. No)	−0.167 (0.284)	0.226 (0.173)	0.868** (0.401)
ATT (Yes vs. No)	−0.178 (0.181)	0.170 (0.166)	0.269 (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 lifting 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.

nutrition outcomes. For instance, households cultivating on low-lying, swamp/marshland mainly planted: okro (55.93%); pepper (42.37%); rice (33.90%); and maize (28.81). Besides, average income from irrigated agriculture for this group was GHS 1457.12 although the income from irrigated agriculture was on average about GHS 678.44. On the other hand, 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%). Furthermore, income from irrigated agriculture for this group was GHS 1348. These results suggest that households using different types of irrigation cultivates either cereals and/or vegetables as their major crops and this leads to differences in income.

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 impact child nutrition is through the availability of diverse foods, which is closely related to nutritional outcomes. The data at hand however do not allow us to investigate this channel in detail. Table 7 reports other possible mechanisms (proxies of income & environmental quality) that irrigation could affect nutrition outcomes. Most of the estimated coefficients of the ATT indicates a positive association, but none of them is statistically significant; except for 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.

5.2. *Other outcomes*

We estimate the impacts of irrigated agriculture on child illness, diarrhea, and fever. As shown in Table 8, children living in irrigating households are more likely to experienced general illness or fever in the last four weeks preceding the surveys (columns 1 & 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", and this shows that the estimated results on nutrition are lower bound. Irrigation systems, for instance, can serve as a breeding ground for mosquitoes that lead to a higher incidence of malaria [6,7].

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 Online Supplementary Materials. Propensity score matching was estimated using the nearest neighbor of four (NN = 4). The results are comparable across different estimation strategies. The PSM results are summarized in Appendices A, B, C and D. Rosenbaum bounds on treatment effects estimates for the PSM results mainly confirm 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 E1 & E2), which was not statistically significant for the IPWRA or PSM estimators. Similarly, results from FE estimates partly confirms those from the RE and CRE, except that the effects on WHZ were not statistically significant (Appendix E3 & E4).

We also explore the option of addressing selection bias issues using the Heckman selection model. We assume that child health and nutrition outcome is 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 are not statistically significant (p-value of 0.483), suggesting that sample selection bias is less likely.

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

Irrigated Agriculture	(1) HH monthly income is high (>GHS 400)	(2) Child ever had NHIS card	(3) Bednet per capita	(4) Improved drinking water	(5)Treat water	(6) Improved sanitation
ATE (Yes vs. No)	0.037 (0.029)	−0.019 (0.031)	−0.033*** (0.013)	0.021 (0.030)	−0.007 (0.023)	0.037 (0.033)
ATT (Yes vs. No)	0.034 (0.034)	0.016 (0.033)	−0.021 (0.015)	0.057* (0.033)	−0.000 (0.030)	−0.010 (0.037)
Observations	*1264*	*1232*	*1090*	*1257*	*1231*	*1245*
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.

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

Irrigated Agriculture	(1) Illness/injury – Yes = 1	(2) Diarrhea –Yes = 1	(3) Fever –Yes = 1
ATE (Yes vs. No)	0.033 (0.031)	−0.001 (0.018)	0.061** (0.027)
ATT (Yes vs. No)	0.054* (0.033)	−0.017 (0.018)	0.066** (0.028)
Observations	*1240*	*1240*	*1240*
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.

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 have improved child nutrition outcomes. Using a panel household survey data and a doubly robust estimator, we find that irrigated agriculture led to large improvements in child nutrition outcomes, with considerable gains for males and under-five children. For instance, a child living with an irrigating household gains 0.23 units of SD in WAZ and 0.27 units of SD in WHZ in the study period. The findings on male children indicate the biases in intrahousehold resource allocation toward this group, which is in concurrence with earlier findings (e.g., Ref. [40]. 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 compared to overhead and other irrigation types. While there is a 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 lifting water from water sources, generate higher nutrition benefits than overhead irrigation type. 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 impacts child nutrition could be increased in demand for environmental quality and health care financing rather than decreases in illness incidences. The latter is not surprising as the results show that irrigated agriculture does not lead to investments in preventive health care (e.g., bednets), leading to a high incidence of self-reported fever cases. Although the results are not statistically significant, diarrhea incidences are consistently lower. Finally, the study identifies several areas for future research on the impacts of irrigation on child nutrition outcomes. The sample for the study is 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. Additionally, although we attempt to reduce selection problems to the extent possible using various econometric techniques, causal interpretation of the results may be biased. This is so because treatment effects models and panel regressions may not be able to address all issues related to endogeneity and therefore, the causal interpretation of empirical findings maybe be viewed with some caution. For instance, 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 policymakers as well as researchers on the nutrition impacts of irrigation in LMICs including Ghana.

Author contribution

Charles Y. Okyere: Conceptualization, Formal analysis, Funding acquisition, Writing – original draft conceived the study and acquired the funding, collected the data and performed part of the statistical analysis, contributed to developing the concept and writing the manuscript, Both authors read and approved the final manuscript. Muhammed A. Usman: Conceptualization, Funding acquisition, Writing – original draft conceived the study and acquired the funding, contributed to developing the concept and writing the manuscript

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to acknowledge the financial support received from the African Economic Research Consortium (AERC), the *Bill and Melinda Gates Foundation*, and Dr. Hermann Eiselen Doctoral Programme of the Fiat Panis Foundation at different stages of the project. We would also like to thank Dr. Abebe Shimeles and the participants of the AERC 50th Biannual Research Workshop for their constructive comments and suggestion. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the funders. All mistakes remain the responsibility of the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wre.2020.100174.

References

[1] A. Abdulai, V. Owusu, E.A. Bakang, Adoption of safer irrigation technologies and cropping patterns: evidence from southern Ghana, Ecol. Econ. 70 (2011) 1415–1423.

[2] N. Akrofi, D. Sarpong, H. Somuah, Y. Osei-Owusu, Paying for privately installed irrigation services in Northern Ghana: the case of the smallholder Bhungroo Irrigation Technology, Agric. Water Manag. 216 (2019) 284–293.

[3] M.A. Akudugu, B.V. Nyamadi, S. Dittoh, Transforming smallholder agriculture in Africa through irrigation: an assessment of irrigation impact pathways in Ghana, in: Conference Paper Presented at the 5th International Conference of the African Association of Agricultural Economists (AAAE), Addis Ababa, Ethiopia, 2016.

[4] H. Alaofè, J. Burney, R. Naylor, D. Taren, Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in northern Benin, Food Nutr. Bull. 37 (2) (2016) 164–175, https://doi.org/10.1177/0379572116639710.

[5] D. Almond, J. Currie, Human capital development before age five, in: O. Ashenfelter, D.E. Card (Eds.), Handbook of Labor Economics, 4B. Elsevier, 2011, pp. 1315–1486.

[6] K. Asayehegn, Negative impact of small-scale irrigation schemes: a case study of Central Tigray Regional State, Ethiopia, Agric. Res. Rev. (Cairo) 1 (3) (2012) 80–85.

[7] K. Asenso-Okyere, F.A. Asante, Jifar Tarekegn, K.S. Andam, Addressing the links among agriculture, malaria, and development in Africa, in: Shenggen Fan, R. Pandya-Lorch (Eds.), Reshaping Agriculture for Nutrition and Health, Intl Food Policy Res Inst (IFPRI), Washington, D.C, 2012, p. 129.

[8] B.B. Balana, J.-C. Bizimana, J.W. Richardson, N. Lefore, Z. Adimassu, B.K. Herbst, Economic and food security effects of small-scale irrigation technologies in northern Ghana, Water Resour. Econ. 29 (2020), https://doi.org/10.1016/j.wre.2019.03.001, 100141.

[9] S. Benin, Trends and Composition of Government Expenditures on Agriculture in Ghana, 1960–2015. Regional Strategic Analysis and Knowledge Support System (ReSAKSS) Issue Note 31, Intl Food Policy Res Inst (IFPRI), Washington, DC, 2019.

[10] T. Benson, Association between irrigated farming and improved nutrition in farm households in Malawi, Agrekon 54 (3) (2015) 62–86.

[11] P. Bhagowalia, D. Headey, S. Kadiyala, Agriculture, income, and nutrition linkages in India: insights from a nationally representative survey, IFPRI Discussion Papers 31 (28) (2012) 1–31.

[12] W.D. Biru, M. Zeller, T.K. Loos, The impact of agricultural technologies on poverty and vulnerability of smallholders in Ethiopia: a panel data analysis, Soc. Indicat. Res. 147 (2020) 517–544, https://doi.org/10.1007/s11205-019-02166-0.

[13] R.E. Black, C.G. Victora, S.P. Walker, Z.A. Bhutta, P. Christian, M. De Onis, R. Uauy, Maternal and child undernutrition and overweight in low-income and middle-income countries, Lancet 382 (9890) (2013) 427–451, https://doi.org/10.1016/S0140-6736(13)60937-X.

[14] J.A. Burney, R.L. Naylor, Smallholder irrigation as a poverty alleviation tool in sub-saharan Africa, World Dev. 40 (1) (2012) 110–123, https://doi.org/10.1016/j.worlddev.2011.05.007.

[15] M.D. Cattaneo, Efficient semiparametric estimation of multi-valued treatment effects under ignorability, J. Econom. 155 (2010) 138–154.

[16] S. Dercon, D.O. Gilligan, J. Hoddinott, T. Woldehanna, The impact of agricultural extension and roads on poverty and consumption growth in fifteen Ethiopian villages, Am. J. Agric. Econ. 91 (4) (2009) 1007–1021.

[17] L. Domenech, C. Ringler, The impact of irrigation on nutrition, health, and gender: a review paper with insights for Africa south of the sahara. IFPRI discussion paper 01259. Available at. http://ssrn.com/abstract=2249812, 2013.

[18] L. Domènech, Improving irrigation access to combat food insecurity and undernutrition: a review, Global Food Security 6 (2015) 24–33, https://doi.org/10.1016/j.gfs.2015.09.001.

[19] M. Filipski, D. Manning, J.E. Taylor, X.D.A. Pradesha, A. Pradesha, Evaluating the Local Economywide Impacts of Irrigation Projects: Feed the Future in Tanzania (IFPRI Discussion Paper 01247), Intl Food Policy Res Inst (IFPRI), Washington, DC, 2013.

[20] N. Gerber, J. von Braun, M.A. Usman, M.M. Hasen, C.Y. Okyere, R. Vangani, D. Wiesmann, Water, Sanitation and Agriculture Linkages with Health and Nutrition Improvement. ZEF – Discussion Papers on Development Policy No. 282, Center for Development Research, Bonn, Germany, 2019.

[21] GhanaWeb, One Village, One Dam not solving irrigation problems – Bongo residents complain, Available at, https://www.ghanaweb.com/GhanaHomePage/NewsArchive/One-Village-One-Dam-not-solving-irrigation-problems-Bongo-residents-complain-730881, 2019. (Accessed 4 October 2019).

[22] M. Grossman, On the concept of health capital and the demand for health, J. Polit. Econ. 80 (2) (1972) 223–255.

[23] Ghana Statistical Service (GSS), Ghana Health Service (GHS), ICF International, Demographic and Health Survey 2014, GSS, GHS, and ICF International, Rockville, Maryland, USA, 2015.

[24] J.H. Humphrey, Child undernutrition, tropical enteropathy, toilets, and handwashing, Lancet 374 (9694) (2009) 1032–1035.

[25] P.G. Katic, R.E. Namara, L. Hope, E. Owusu, H. Fujii, Rice and irrigation in West Africa: achieving food security with agricultural water management strategies, Water Resour. Econ. 1 (2013) 75–92, https://doi.org/10.1016/j.wre.2013.03.001.

[26] A. Kirk, T. Kilic, C. Carletto, Composition of household income and child nutrition outcomes: evidence from Uganda, World Dev. 109 (2018) 452–469, https://doi.org/10.1016/j.worlddev.2017.03.023.

[27] V. Kirogo, K. Wambui, N. Muroki, The role of irrigation on improvement of nutritional status of young children in central Kenya, Afr. J. Food Nutr. Sci. 7 (2) (2007) 1–16.

[28] M. Kremer, J. Leino, E. Miguel, A.P. Zwane, Spring cleaning: rural water impacts, valuation and property rights institutions, Q. J. Econ. 126 (2011) 145–205, https://doi.org/10.1093/qje/qjq010.

[29] M. Lipton, J. Litchfield, J.M. Faurès, The effects of irrigation on poverty: a framework for analysis, Water Pol. 5 (2003) 413–427.

[30] L.S.O. Liverpool-Tasie, Is fertiliser use inconsistent with expected profit maximization in sub-Saharan Africa? "Evidence from Nigeria", J. Agric. Econ. 68 (1) (2017) 22–44, https://doi.org/10.1111/1477-9552.12162.

[31] J. Manda, C. Gardebroek, E. Kuntashula, A.D. Alene, Impact of improved maize varieties on food security in eastern Zambia: a doubly robust analysis, Rev. Dev. Econ. 22 (2018) 1709–1728.

[32] J.H. Mangisoni, Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: a case study of Blantyre and Mchinji districts, Int. J. Agric. Sustain. 6 (4) (2008) 248–266, https://doi.org/10.3763/ijas.2008.0306.

[33] E. Mangyo, The effect of water accessibility on child health in China, J. Health Econ. 27 (2008) 1343–1356.

[34] D.K. Mekonnen, J. Choufani, E. Bryan, A.R. Abizari, C. Ringler, J. Amikuzuno, Irrigation-nutrition Linkages: Evidence from Northern Ghana (IFPRI Discussion Paper 01887), Intl Food Policy Res Inst (IFPRI), Washington, DC, 2019, https://doi.org/10.2499/p15738coll2.133515. Retrieved from.

[35] M. Mendes, L. Paglietti, D. Jackson, G. Altozano, Ghana: Irrigation Market Brief, FAO and IFC, Rome, 2014.

[36] Ministry of Food & Agriculture (MoFA), Agriculture in Ghana: Facts and Figures 2016. Statistics, Research, and Information Directorate (SRID), MoFA, Accra, Ghana, 2017.

[37] Y. Mundlak, On the pooling of time series and cross section data, Econometrica (1978) 69–85, https://doi.org/10.2307/1913646.

[38] G.M.A. Nonvide, Irrigation adoption: a potential avenue for reducing food insecurity among rice farmers in Benin, Water Resour. Econ. 24 (2018) 40–52, https://doi.org/10.1016/j.wre.2018.05.002.

[39] C.Y. Okyere, Water Quality in Multipurpose Water Systems, Sanitation, Hygiene and Health Outcomes in Ghana (Doctoral thesis), University of Bonn, Germany, 2018. Available at, http://hss.ulb.uni-bonn.de/2018/4854/4854.htm.

[40] S. Pal, An analysis of childhood malnutrition in rural India: role of gender, income and other household characteristics, World Dev. 27 (7) (1999) 1151–1171.

[41] S. Passarelli, D. Mekonnen, E. Bryan, C. Ringler, Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania, Food Security 10 (4) (2018) 981–997.

[42] Scaling-Up Nutrition, Nutrition at the heart of the SDGs, Available at, www.scalingupnutrition.org, 2017. (Accessed 5 July 2017).

[43] S.B. Sorenson, C. Morssink, P.A. Campos, Safe access to safe water in low income countries: water fetching in current times, Soc. Sci. Med. 72 (9) (2011) 1522–1526, https://doi.org/10.1016/j.socscimed.2011.03.010.

[44] J.A. Tambo, J. Mockshell, Differential impacts of conservation agriculture technology options on household income in sub-saharan Africa, Ecol. Econ. 151 (2018) 95–105.

[45] J.A. Tambo, B. Uzayisenga, I. Mugambi, M. Bundi, S. Silvestri, Plant clinics, farm performance and poverty alleviation: panel data evidence from Rwanda, World Dev. 129 (2020), https://doi.org/10.1016/j.worlddev.2020.104881. Available online.

[46] C. Tinonin, C. Azzarri, B. Haile, M. Comanescu, C. Roberts, S. Signorelli, Africa RISING Baseline Evaluation Survey (ARBES) Report for Ghana, Intl Food Policy Res Inst (IFPRI), Washington, DC, 2016. Retrieved from, http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130390.

[47] M.A. Usman, N. Gerber, Assessing the effect of irrigation on household water quality and health: a case study in rural Ethiopia, Int. J. Environ. Health Res. (2019), https://doi.org/10.1080/09603123.2019.1668544.

[48] M.A. Usman, N. Gerber, Irrigation, drinking water quality, and child nutritional status in northern Ethiopia, J. Water, Sanit. Hyg. Dev. 10 (3) (2020) 425–434, https://doi.org/10.2166/washdev.2020.045.

[49] M.A. Usman, N. Gerber, E.H. Pangaribowo, Drivers of microbiological quality of household drinking water–a case study in rural Ethiopia, J. Water Health 16 (2) (2018) 275–288, https://doi.org/10.2166/wh.2017.069.

[50] M.A. Usman, N. Gerber, J. von Braun, The impact of drinking water quality and sanitation on child health: evidence from rural Ethiopia, J. Dev. Stud. 55 (10) (2019) 2193–2211, https://doi.org/10.1080/00220388.2018.1493193.

[51] M.A. Usman, Water, Sanitation and Agriculture: Linkages and Impacts on Health and Nutritional Outcomes in Rural Ethiopia (Doctoral Thesis), University of Bonn, Germany, 2017. Retrieved from, http://hss.Ulb.Uni-bonn.De/2017/4825/4825.Pdf.

[52] M. Van Den Berg, R. Ruben, Small-Scale irrigation and income distribution in Ethiopia, J. Dev. Stud. 42 (5) (2006) 868–880, https://doi.org/10.1080/00220380600742142.

[53] W. van Der Hoek, F. Konradsen, J.H.J. Ensink, M. Mudasser, P.K. Jensen, Irrigation water as a source of drinking water: is safe use possible? Trop. Med. Int. Health 6 (1) (2001) 46–54, https://doi.org/10.1046/j.1365-3156.2001.00671.x.

[54] J. von Braun, D. Puetz, P. Webb, Irrigation Technology and Commercialization of Rice in the Gambia: Effects on Income and Nutrition (IFPRI Research Report 75), 1989. Washington, DC.

[55] J. Wolf, A. Prüss-Ustün, O. Cumming, J. Bartram, S. Bonjour, S. Cairncross, L. Fewtrell, Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low-and middle-income settings: systematic review and meta-regression, Trop. Med. Int. Health 19 (8) (2014) 928–942.

[56] J.M. Wooldridge, Econometric Analysis of Cross Section and Panel Data, second ed., MIT Press, Cambridge, MA, 2010.

[57] H. Xie, L. You, B. Wielgosz, C. Ringler, Estimating the potential for expanding smallholder irrigation in sub-Saharan Africa, Agric. Water Manag. 131 (2014) 183–193, https://doi.org/10.1016/j.agwat.2013.08.011.

[58] L. You, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, T. Zhu, Y. Sun, What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach, Food Pol. 36 (6) (2011) 770–782, https://doi.org/10.1016/j.foodpol.2011.09.001.

[59] W. Zeweld, G.V. Huylenbroeck, A. Hidgot, M.G. Chandrakanth, S. Speelman, Adoption of small-scale irrigation and its livelihood impacts in northern Ethiopia, Irrigat. Drain. 64 (5) (2015) 655–668, https://doi.org/10.1002/ird.1938.

[60] J. Zhang, The impact of water quality on health: evidence from the drinking water infrastructure program in rural China, J. Health Econ. 31 (2012) 122–134.

[61] Ghana Statistical Services (GSS). Rebased 2013-2018 Annual Gross Domestic Product, April 2019 Edition, Ghana Statistical Services, Accra, Ghana, 2019.