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Is Reliable Water Access the Solution to Undernutrition?

A Review of the Potential of Irrigation to Solve Nutrition and Gender Gaps in Africa South of the Sahara

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ABSTRACT

Interventions aimed at increasing water availability for livelihood and domestic activities have great potential to improve various determinants of undernutrition, such as the quantity and diversity of foods consumed within the household, income generation, and women's empowerment. However, current evidence on the topic is diluted across many different publications. This paper aims to connect the dots and review the literature available on the linkages between irrigation and food security, improved nutrition, and health.

We conclude that the evidence remains insufficient to draw broad conclusions due to the low number of rigorous studies that can be used to assess the linkages. Based on the limited evidence, six factors that should be taken into account in irrigation development to address nutrition and gender gaps with a focus on Africa south of the Sahara are identified: (1) food security and nutrition gains should be stated goals of irrigation programs; (2) training programs and awareness campaigns should accompany irrigation interventions to promote nutrient-dense food production and consumption as well as minimization of health risks; (3) multiple uses of irrigation water should be recognized in order to improve access to water supply and sanitation and livestock and aquatic production; (4) women's empowerment and women's participation in irrigation programs should be promoted; (5) homestead food production should be encouraged; and (6) policy synergies between different sectors (agriculture, nutrition, health, water supply and sanitation, education) should be sought.

Keywords: irrigation, nutrition, health, women's empowerment, Africa south of the Sahara

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1. INTRODUCTION

Malnutrition rates in Africa south of the Sahara (SSA) are still high compared to other regions. Stunting, wasting, and underweight currently affect 39.6, 9.4, and 21.4 percent of the children under five in SSA due to lack of nutritious foods and high incidence of disease (UNICEF, WHO, and World Bank 2012). Along these lines, insufficient progress on the Millennium Development Goal on hunger reduction is being shown in several SSA countries. In SSA, more than 60 percent of the population lives in rural areas, and rainfed agriculture is the main or only source of livelihood for most rural households (Faurès and Santini 2008). Due to lack of access to water, agricultural production is normally interrupted during the dry season, when many farmers must rely on food stocks accumulated during the rainy season and/or on food purchases. Furthermore, rainfed cereal crops (for example, maize, sorghum, or millet) are the main source of food and income of many smallholders in SSA, but these have limited nutritional content and low market value and, as a result, have low poverty and malnutrition reduction potential (Burney, Naylor, and Poste 2013).

Irrigated agriculture can be an important entry point for malnutrition reduction because water is frequently a limiting factor for crop and livestock production. Irrigation can also reduce vulnerability to droughts and climate change, which are both important drivers of hunger and undernutrition. In SSA, irrigation rates are among the lowest in the world, and therefore the potential for expanding irrigated agriculture in the region is still large. In the developing world, Asia has the greatest share of irrigated land—37 percent of the total cultivated area is equipped for irrigation—and Latin America is second, with 14 percent of cultivated area irrigated (FAOSTAT 2009, quoted in You et al. 2010). In SSA, only a small share of cultivated area—approximately 6 percent—is irrigated, and this is mostly concentrated in three countries: Madagascar, South Africa, and Sudan (You et al. 2010; Frenken 2005; Svendsen, Ewing, and Msangi 2009).

Africa's large-scale irrigation potential was estimated at 15 million hectares, and potential for a complementary small-scale component was estimated at 7 million hectares (You et al. 2011). Xie et al. (2014), focusing on various smallholder technologies, estimated a total potential for motor pumps, treadle pumps, small reservoirs, and communal river diversions of 30, 24, 22, and 20 million hectares, respectively, reaching between 113 and 369 million rural beneficiaries across the region. Even though the potential of smallholder irrigation in the region is large, there are significant obstacles, including lack of public support and investment, to achieving the full potential (Giordano et al. 2012).

The potential of irrigation to improve nutrition and other outcomes also depends on a series of other factors such as the water source (groundwater, surface water, ponds), relative water availability (single season, supplementary, or full), type of technology (drip or sprinkler systems, deep or shallow tube wells, treadle pumps), size of the system (large-scale versus small-scale), access to agricultural inputs (land, credit, seeds, fertilizer, and so on), socioeconomic features of the household, and institutional rules governing water access and maintenance of water systems (Lipton, Litchfield, and Faurès 2003).

Irrigation can provide greater availability and stability of food supplies during the dry season and can enable crop diversification, including greater availability and consumption of micronutrient-rich vegetables and fruits. Other benefits include income generation, improved water supply, and women's empowerment. Irrigation in most contexts has multiple uses, as described in Meinzen-Dick (1997, 1998), such as providing water for bathing, washing, handicraft making, livestock watering, and fish culture, to name a few. In view of the large potential for irrigation expansion in SSA and the potential of irrigation to enhance food security and nutrition outcomes, irrigation could become an important component of nutrition-sensitive programs to help reduce undernutrition incidence in the region.

The success of single-sector approaches such as dietary or micronutrient supplementation and the promotion of caregiving practices to improve children's nutrition and health has been mixed (Humphrey 2009; Dewey and Adu-Afarwuah 2008). At the same time, nutrition-sensitive programs that address some of the underlying causes of undernutrition, such as agricultural interventions and safety net programs, are

becoming increasingly popular (Ruel and Alderman 2013). Irrigation interventions would fall within this second group, although to date irrigation programs have rarely been implemented as nutrition-sensitive interventions, as policymakers and donors continue to consider them only as agricultural technology strategies.

Water access can be provided through small-scale irrigation but also through domestic water supply. Research has shown that advances in equitable access and use of safe water and basic sanitation services and improved hygiene practices, generally grouped together as "WASH," are needed to reduce child mortality, improve health and education outcomes, and contribute to reduced poverty and sustainable development (UNICEF 1990; UN 2006). The direct linkage of WASH with nutrition has also long been recognized. Poor WASH is considered the main cause of diarrhea and other conditions such as environmental enteropathy, which has recently received renewed attention. Diarrhea results in about 2 million deaths of under-fives annually, causes and exacerbates malnutrition, and contributes to stunting (UN 2006). The role of WASH in addressing nutrition and gender outcomes has been well documented and will therefore not be addressed in depth here (see, for example, Esrey et al. 1991; Fewtrell and Colford 2005).

We argue that interventions aimed at increasing water availability for livelihood and domestic activities have great potential to improve various determinants of undernutrition, such as the quantity and diversity of foods consumed within the household, income generation, and women's empowerment. In order to test this hypothesis, we conduct a literature review on the available evidence of the impacts of irrigation on nutrition, health, and gender outcomes. Gender variables are given special consideration because women's roles in agriculture and within the household are considered a critical determinant of nutrition and health outcomes (Meinzen-Dick et al. 2012; Fafchamps, Kebede, and Quisumbing 2009). Several review papers have analyzed the available evidence regarding the effect of agricultural interventions on nutrition outcomes, particularly of children and women (Berti, Krasevec, and FitzGerald 2003; World Bank 2007; Masset et al. 2012; Girard et al. 2012; Webb 2013); however, with the exception of home gardens, irrigation interventions were rarely considered in these reviews. This paper aims to address this gap by reviewing the existing literature on the topic. It builds on and expands upon an earlier background paper prepared by Domenech and Ringler (2013).

The paper is structured as follows. In Section 2, the main impact pathways between irrigation and improved nutrition and health are identified. The methodology is described in Section 3. In Section 4, the main results and research gaps encountered for the identified pathways are summarized. Some suggestions on how to design more nutrition-sensitive irrigation interventions are provided in Section 5. The paper ends with some concluding remarks.

2. IMPACT PATHWAYS FROM IRRIGATION TO IMPROVED NUTRITION AND HEALTH

The financial, human, physical, social, and natural capital and the assets available to the household determine the type of livelihoods households rely on. If water is available and farmers have access to it, irrigated agriculture can become an important livelihood strategy for rural households. Irrigation water may add great value to cultivated lands, especially in areas where rainfall is scarce or erratic. At the same time, some risks or undesired outcomes can also result from irrigation interventions if programs disregard the environmental, social, economic, and political context they are embedded in.

The use of water for irrigation can increase agricultural productivity significantly, especially during the dry season. The Agricultural Water Management Solutions project estimated large yield improvements from smallholder irrigation in SSA. Irrigated maize yields could increase by 141–195 percent and paddy yields by 270–283 percent, compared to rainfed yields based on an ex ante smallholder irrigation technology assessment (Xie et al. 2014). Irrigation would also increase labor demand, particularly in the lean or dry season. However, use of agrochemicals would also increase.

The number and type of crops that farmers grow also changes with irrigated agriculture. The type of technology used, the size of landholding, and the irrigation system (large-scale versus small-scale) will influence crop selection and diversity (monoculture versus vegetables and fruits). Smallholder irrigation systems are frequently used to grow micronutrient-rich vegetables, fruits, and other cash crops during the dry season. As a result, small-scale irrigation can provide greater availability and stability of food supplies and crop diversification (Molden 2007).

Besides greater availability of foods, other factors are also important determinants of food security and related nutrition outcomes (Berti, Krasevec, and FitzGerald 2003). Food security is usually defined according to four pillars, or dimensions, that need to be maintained over time: *food availability, access, utilization,* and *stability* (FAO 2009). *Food availability* refers to the existence of adequate food supply from domestic agriculture or food imports. *Food access* involves a household's ability to obtain food in the market or from other sources, which is usually determined by a household's income and the existence of markets. *Food utilization* refers to the ability to consume nutritious foods and benefit from them (Burney et al. 2010). And finally, *food stability* refers to the ability to obtain food over time.

Irrigated agriculture is frequently used to grow nutritious vegetables and fruits throughout the year, with important nutritional and health benefits for the households consuming them. Irrigation water can also be used to grow irrigated fodder or to support livestock-rearing activities leading to increased availability of animal-source foods within the household. Consumption of dark green leafy vegetables and animal-source foods can help reduce anemia incidence due to their high iron content. Iron deficiency is a risk factor for maternal mortality and is responsible for 115,000 deaths annually and 0.4 percent of global total disability-adjusted life years (DALYs) (Black et al. 2008). Orange-fleshed sweet potatoes, pumpkins, and other vitamin A–rich foods can reduce night blindness and susceptibility to illness. Deficiencies of vitamin A and zinc cause 0.6 million and 0.4 million annual deaths, respectively, and a combined 9 percent of global childhood DALYs (Black et al. 2008). Additionally, if children are exposed prenatally and during the first two years of life to more nutritious diets, the number of children affected by stunting will likely decrease (UNICEF 2013).

Vegetables, fruits, and animal-source foods are usually marketable and highly profitable products and, consequently, they can also be an important source of income for the household. However, the lack of access to reliable markets in some remote communities may hinder income generation from irrigation activities (Chazovachii 2012). Having access to information about the demand and supply of agricultural products, how to preserve them, and the right time to sell these perishable products without loss of quality is also critical for smallholders using irrigation. Ethiopian households with access to market information earned US$1,297 more than households that had deficient market information (Aseyehegn, Yirga, and Rajan 2012). Large, successful irrigation programs can also affect food prices. Nonirrigators, in both rural

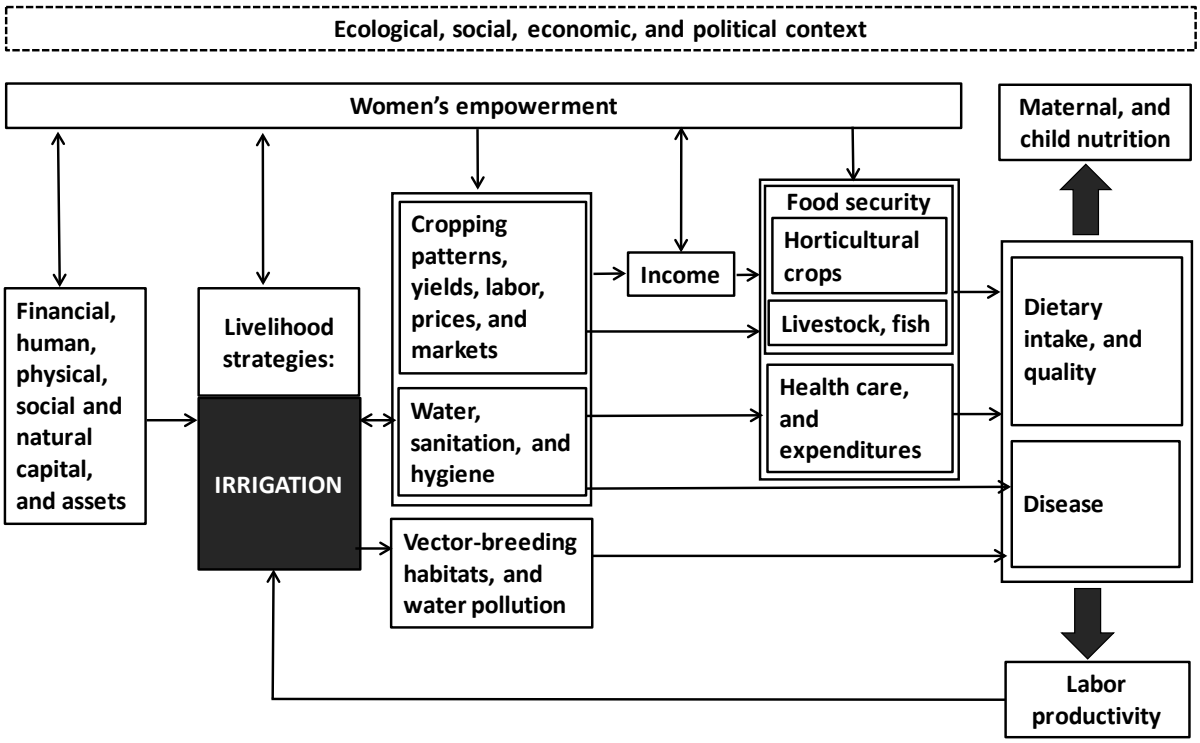
and urban areas, may benefit from reduced prices due to greater availability of staples and other food products (Lipton, Litchfield, and Faurès 2003).

Women's roles in agriculture and within the household also have an important influence on household food security and nutrition, as women tend to prioritize household nutrition and health over other expenditures. If women are farming their own plots and have access to irrigation technologies, then the productivity of female-managed plots may increase, and income from the increase in productivity may also grow, which is likely to lead to women's empowerment and nutritional gains within the household (Njuki et al. 2014; Burney et al. 2010).

In addition to crop irrigation, irrigation water might be employed for other purposes such as drinking and other domestic uses, handicraft making, sanitation, and livestock rearing, with associated benefits for health and nutrition (Meinzen-Dick 1997, 1998). Women may particularly benefit from improved access to water because women are usually responsible for water-collection chores. The time saved may allow women to participate more actively in income-generating, caregiving, and social activities (Upadhyay, Samad, and Giordano 2005; Njuki et al. 2014). Better water access, sanitation, and hygiene will also lead to a healthier environment and a reduced incidence of disease, with resulting improved children's growth and development (Humphrey 2009; Chambers and Von Medeazza 2013).

Overall, five main impact pathways linking irrigation to nutrition and health outcomes are identified in this paper: irrigation as a source of more and more diverse foods (through increased agricultural productivity and crop diversification); irrigation as a source of income (from market sales and employment generation); irrigation as a source of water supply, sanitation, and hygiene (through multiple water use); irrigation as new vector-breeding habitat and a source of water pollution (from agrochemicals); and irrigation as an entry point for women's empowerment (through increased asset ownership and control over resources) (Figure 2.1).

Figure 2.1 Impact pathways from irrigation to better nutrition and health



Source: Author.

3. METHODOLOGY

We searched for peer-reviewed papers and gray literature using the following keywords alone or in combinations*: irrigation, nutrition, health, food security, anthropometrics, dietary diversity, women's empowerment, gender, water supply, sanitation, livestock*, and *irrigated fodder*. We used Google Scholar to conduct the search. Some studies were also found by cross-checking the reference lists of selected studies and by discussing the review project with other colleagues.

The final list of studies included in the review can be found in Table 3.1. We kept only studies that used primary data collection and included some measurement of food security, nutrition, health, and gender outcomes of irrigation interventions. Another inclusion criterion was a description of methods in sufficient detail. Original papers that measured the impact of home gardens on these outcomes were also included in the review, as home gardens typically need to be watered periodically, especially in arid and semiarid areas. Home gardens are also of particular interest for this review because they have great potential to increase household food security. Fruits and vegetables grown in these plots are usually kept for home consumption or sold in local markets (Girard et al. 2012; Iannotti, Cunningham, and Ruel 2009). Furthermore, women are frequently in control of home garden products, and therefore home gardens can be an important entry point for women's empowerment (Bushamuka et al. 2005).

In total, 27 papers were systematically reviewed. Almost all the studies reviewed had their study focus in SSA, except for 5 that studied Asian cases. Dams and canal irrigation were the main type of irrigation used in 12 studies, while small-scale private irrigation was used in 8 studies. Micro-irrigation technologies were the main focus of 5 studies, home gardens of 4, and irrigation with wastewater of 1. Information on the main features of the irrigation system was missing in the rest of the studies (Table 3.1).

The most common evaluation method used in the papers reviewed involved a comparison of outcomes between irrigation adopters and nonadopters. Sample selection bias was an important limitation of the evaluation design in many of the papers reviewed, but some of the papers minimized this problem by using propensity score matching methods. Self-selection bias is a common limitation of this kind of evaluation study because randomizing the households adopting irrigation technologies is often difficult. Households with higher education and income levels are more likely to adopt irrigation technologies and, accordingly, the outcome variables measured (for example, nutrition outcomes) may differ due to these unobservable characteristics and not due to the use of irrigation. Panel data (before/after) analysis was conducted in six studies in order to monitor any changes induced by the intervention over time. Only three studies (four papers) followed the most typical experimental design, including both the before/after analysis and the adopter/nonadopter comparison. Some studies also collected qualitative data to allow for more descriptive analyses of irrigation outcomes.

Table 3.1 Main features of the studies reviewed

Source	Study area	Type of irrigation	Main irrigated crops grown	Sample size	Measuring food security / nutrition outcomes main goal?	Experimental design	
						Adopters and nonadopters comparison	Before/after comparison
Adeoti et al. 2007	Ghana	Treadle pumps	Vegetables	108 farmers	No	Yes	No
Aseyehegn, Yirga, and Rajan 2012	Ethiopia (Tigray)	Micro-irrigation dams	Cereals and vegetables	130 households	No	Yes	No
Bagson and Wuleka Kuuder 2013	Ghana (Kokoligu)	Dams	Vegetables (tomatoes, cabbage, lettuce, okra)	50 household heads	Yes	No	No
Benefice and Simondon 1993	Senegal	Irrigation dams (flood irrigation)	Rice, tomatoes, and onions	110 extended family units	Yes	No	Yes
Burney and Naylor 2012	Benin	Solar-powered drip irrigation	Vegetables in communal gardens	120 households	No	Yes	Yes
Burney et al. 2010	Benin	Solar-powered drip irrigation	Vegetables in communal gardens	120 households	Yes	Yes	Yes
Clarke et al. 1997	Ghana	NA	NA	188 individuals	No	Yes	No
Dillon 2008	Mali	Canal irrigation with motorized pumps	Rice	245 households	No	Yes	Yes
Ersado 2005	Ethiopia (Tigray)	Micro-irrigation dams	Cereals and vegetables	730 households	No	Yes	No
FAO 2000	Zimbabwe	Surface and sprinkle irrigation	Horticultural crops	10 case studies	No	No	No
Kabunga, Ghosh, and Griffiths 2014	Uganda	NA	Vegetables and fruits	3,630 households	Yes	Yes	No
Kirogo, Kogi-Makau, and Muroki 2007	Kenya	Surface irrigation	Horticultural production	118 households	Yes	Yes	No
Mangisoni 2008	Malawi	Treadle pumps	Maize, beans, and vegetables	200 households	Yes	Yes	No
Namara, Upadhyay, and Nagar 2005	India	Drip and sprinkler irrigation from groundwater	Fruits, groundnut, cotton, and vegetables	448 households	No	Yes	No
Namara et al. 2011	Ghana	Shallow groundwater	Tomatoes and peppers	420 farmers	No	Yes	No

Table 3.1 Continued

Source	Study area	Type of irrigation	Main irrigated crops grown	Sample size	Measuring food security / nutrition outcomes main goal?	Experimental design	
						Adopters and nonadopters comparison	Before/after comparison
Nkhata 2014	Malawi	Canal irrigation	Rice, maize, soybean, and cowpea	412 households	No	Yes	No
Njuki et al. 2014	Tanzania and Kenya	Groundwater irrigation pumps	Vegetables	358 individuals	No	No	No
Olney et al. 2009	Cambodia	Home gardens	Fruits and vegetables	500 households	Yes	Yes	Yes
Peter 2011	Swaziland	Surface water	Sugarcane and vegetables	NA	Yes	No	No
Sinyolo, Mudhara, and Wale 2014	South Africa	Canal irrigation	Maize and vegetables	256 households	Yes	Yes	No
Srinivasan and Reddy 2009	India	Irrigation with wastewater	Vegetables, para grass, and rice	471 households	No	Yes	No
Steiner-Asiedu et al. 2012	Ghana	Irrigation dams	NA	397 mother-child pairs	No	Yes	No
Upadhyay, Samad, and Giordano 2005	Nepal	Drip irrigation	Vegetables	131 households	No	No	No
van den Bold et al. 2013	Burkina Faso	Home gardens	NA	220 households	Yes	Yes	Yes
Von Braun, Puetz, and Webb 1989	The Gambia	Pumps and tidal irrigation	Rice	900 farmers (214 households)	No	Yes	No
van der Hoek, Feenstra, and Konradsen 2002	Pakistan	Canal irrigation	NA	200 households	Yes	No	No
van Koppen, Hope, and Colenbrander 2012	Ghana and Zambia	Small-scale private irrigation	High-value crops	734 households	No	Yes	No

Source: Compiled by author.

Note: NA = not available.

4. LINKAGES BETWEEN IRRIGATION, NUTRITION, HEALTH, AND GENDER

Irrigation can lead to crucial changes in the livelihood and food security of smallholders. The four food security dimensions—food availability, access, utilization, and stability—are likely to change as a result of increased water availability for crop production and other uses. Irrigation can have a direct impact on *food availability* because of increased productivity and changes in cropping patterns. Moreover, irrigation will likely increase the *stability* of the food supply because irrigation's main role is to enhance water control, thus reducing or eliminating potentially adverse impacts on production from too little rain. However, do more food available and possibly more income translate into increased *food access* and *utilization*? Greater availability of food can certainly favor greater food intake, but this might not always be true in an intrahousehold setting. Irrigated crops are often cash crops, and cash crops are often men's domain. If decisions regarding the crop are in male hands, including the sale and income from the sale, then intrahousehold food and nutrition outcomes might not improve (Quisumbing et al. 1995). Thus, gender dynamics and women's roles in irrigated agriculture are important determinants of food access and utilization.

At the same time, the consumption of more nutritious foods might not be sufficient to achieve normal growth and cognitive development in children. Nutritious diets are certainly a requirement for children's healthy growth, but other conditions such as a healthy environment are also needed. Irrigation can have a dual effect on the environment, improving sanitary and water supply conditions but also competing with or polluting domestic water resources and increasing the incidence of some water-borne diseases, such as malaria. In the next section we attempt to explore all these linkages for the case of irrigation, drawing on the existing literature on the topic.

Irrigation Use and Increased Agricultural Productivity

Irrigation can improve crop productivity in three main ways: reduced crop loss due to access to more reliable water supply, multiple cropping as a result of being able to plant during the dry/lean season, and a greater area of cultivated land due to the use of areas where rainfed production was formerly unfeasible (Lipton, Litchfield, and Faurès 2003). Meeting crop water demands on time itself increases crop yields under irrigated compared to rainfed conditions. However, depending on the location, much of the yield increase is due to increased application of complementary inputs under water-secure conditions. Moreover, irrigated varieties are generally higher yielding than rainfed varieties, as water control allows for better application of complementary agricultural inputs, such as fertilizers and pesticides; much research and development effort has therefore been expended on varieties grown in irrigated environments.

Agricultural productivity gains will also depend on the type of irrigation systems and inputs used. Micro-irrigation technologies, for example, can lead to yield gains of up to 100 percent over conventional irrigation systems (Burney et al. 2010).

Out of the 27 studies used in the review, 13 gathered some data on agricultural productivity (Table 4.1). However, only a few studies included rainfed and irrigated agriculture productivity comparisons. In Ethiopia, Aseyehegn, Yirga, and Rajan (2012) documented that farmers using irrigation systems produced crops twice, and sometimes even three times, per year as opposed to a single cropping season with rainfed agriculture. FAO (2000) analyzed differences in agricultural productivity between rainfed and irrigated systems in ten smallholder irrigation schemes in Zimbabwe. Higher yields than those obtained with rainfed agriculture were reported in five of the irrigation schemes evaluated. For instance, maize yields in one of the schemes studied were between 6 and 9 tons per hectare, compared to 1 to 2 tons per hectare under rainfed conditions. The rest of the schemes showed yields that were lower or comparable to those of rainfed agriculture. These low yields were attributed to lack of inputs and little commitment of farmers to the irrigation scheme (FAO 2000). Nkhata (2014) also compared yield differences between irrigation adopters growing rice and maize and nonadopters in Malawi. Rice yields were higher among irrigation adopters, even though nonadopters had larger landholdings. Nonadopters explained in informal interviews that floods and droughts affected their rice yields.

Table 4.1 Variables analyzed in the studies reviewed

Source	Agricultural production	Income	Livestock	Labor	FS/DI	Anthropo-metrics	Clinical indicators	Morbidity indicators	WASH	GC
Adeoti et al. 2007	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes
Aseyehegn, Yirga, and Rajan 2012	No	Yes	Yes	Yes	No	No	No	Yes	No	Yes
Bagson and Wuleka Kuuder 2013	No	Yes	No	No	Yes	No	No	No	No	No
Benefice and Simondon 1993	No	No	No	No	Yes	Yes	No	No	No	No
Burney and Naylor 2012	No	Yes	Yes	No	Yes	No	No	No	No	Yes
Burney et al. 2010	Yes	Yes	No	No	Yes	No	No	Yes	No	No
Clarke et al. 1997	No	No	No	No	No	No	Yes	Yes	No	No
Dillon 2008	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Ersado 2005	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
FAO 2000	Yes	Yes	No	Yes	Yes	No	No	No	No	Yes
Kabunga, Ghosh, and Griffiths 2014	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Kirogo, Kogi-Makau, and Muroki 2007	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Mangisoni 2008	No	Yes	Yes	Yes	Yes	No	No	No	No	No
Namara, Upadhyay, and Nagar 2005	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes
Namara et al. 2011	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Nkhata 2014	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes
Njuki et al. 2014	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
Olney et al. 2009	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No
Peter 2011	No	Yes	No	No	Yes	No	No	No	No	No
Sinyolo, Mudhara, and Wale 2014	Yes	Yes	Yes	No	Yes	No	No	No	No	No
Srinivasan and Reddy 2009	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes
Steiner-Asiedu et al. 2012	No	No	No	No	Yes	Yes	Yes	No	No	No
Upadhyay, Samad, and Giordano 2005	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
van den Bold et al. 2013[1]	No	No	Yes	No	No	No	No	No	No	Yes
Von Braun, Puetz, and Webb 1989	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
van der Hoek, Feenstra, and Konradsen 2002	No	No	No	No	No	Yes	No	Yes	Yes	No
Van Koppen, Hope, and Colenbrander 2012	No	No	No	Yes	No	No	No	No	No	Yes

Source: Compiled by author.

Notes: NA = not available; FS/DI = Food security/ dietary intake WASH = water, sanitation, and hygiene; GC = Gender considerations. 1- Other outcomes were evaluated in a broader study but not reported in this paper.

An increase in agricultural productivity as a result of irrigation adoption can lead to increased food availability either for own consumption or for marketing and income generation. Mangisoni (2008) compared the annual income per hectare of treadle pump users and nonusers in Malawi. The net farm income per hectare was US$770 for treadle pump users compared to US$131 for nonusers. The paper also explored the impact of irrigation on food availability.

As a result of increased agricultural productivity, demand for labor within the household and in neighboring communities may also increase, which is particularly significant during the dry season because job opportunities are less abundant. Thus, irrigation systems can increase the purchasing power of seasonal workers and members of low-income households, who may decide to use the additional income to purchase nutritious foods. Namara et al. (2011) studied the impact of shallow groundwater irrigation on labor demand. In the 35 communities included in the study from the White Volta Basin in Ghana, shallow groundwater irrigation created a demand for labor estimated at 214 full-time equivalent workers per year during a season of three to four months when employment alternatives were almost nonexistent in the region. The total contribution of shallow groundwater irrigation to the economy of the 35 communities surveyed was estimated at US$1.1 million. In Zimbabwe, the workers in the ten irrigation schemes evaluated were mostly paid in kind, which was shown to have positive benefits in terms of food security and nutrition (FAO 2000).

Irrigation Use and Increased Crop Diversification

The types of crops grown are also likely to change with the introduction of irrigated agriculture because new crops can be planted in a second season and greater water availability enables farmers to grow crops that would be unsuitable for cultivation under rainfed conditions. However, irrigation adoption can sometimes also lead to monocropping, as reported by Hossain, Naher, and Shahabuddin (2005), who correlated the expansion of shallow wells for small-scale irrigation in Bangladesh with an increase in monocropping of rice and a reduction in the production of pulses and oilseeds, which were both important micronutrient and protein sources.

Cash crops are frequently grown on irrigated lands. Namara, Upadhyay, and Nagar (2005) reported cropping pattern changes in India after the installation of micro-irrigation technologies, with micro-irrigation adopters producing more diverse crops, including high-value and water-intensive crops, than farmers using traditional irrigation methods. Cash crops are typically sold in the market and can result in additional income to former subsistence farmers. Growing cash crops is also important in order to make irrigation worthwhile, as the operation and maintenance costs of irrigation systems are typically high (FAO 2000). Nkhata (2014) compared the income of households using irrigation to grow one crop only (rice) and households growing two crops (rice and maize) in the Bwanje Valley Irrigation Scheme in Malawi. Agricultural income was 34 percent higher for households growing two crops, as maize was usually used for self-consumption and surplus rice was sold in the market. However, no differences were observed in the daily per capita caloric intake of the two groups.

Irrigation can be very important to boost vegetable production in countries with low vegetable production and consumption. For example, in Burkina Faso the spread in the use of buckets, watering cans, and small motor pumps contributed to an increase in vegetable production from 60,000 tons in 1996 to 160,000 tons in 2005 (Fraiture and Giordano 2014). In most of the papers reviewed, irrigation is either exclusively or to some extent used to grow vegetables and fruits (Table 3.1).

Given the continued limited supply options in much of Africa, farmers can easily sell vegetables and fruits locally to gain additional income, with additional positive nutritional impacts on the rest of the community (Burney, Naylor, and Poste 2013). A study of the impact of treadle pumps in East Africa revealed that irrigators sold a greater proportion of irrigated crops as compared with rainfed crops. In Kenya and Tanzania, 73 percent and 83 percent, respectively, of the irrigated crops produced by men were commercialized. A significant share of the crops grown (tomato, kale, cabbage, amaranth) was sold in the local village market or to neighbors, thus increasing food availability in the community (Nkonya et al. 2011).

From a nutritional point of view, vegetables and fruits are very valuable products because of their high iron, vitamin A, zinc, and other micronutrient content. Homestead food production programs implemented by Helen Keller International and others successfully improved the amount of vegetables produced by intervention households (Olney et al. 2009; Iannotti, Cunningham, and Ruel 2009). Because an important share of the food produced in homestead gardens is consumed within the household, homestead gardens can contribute significantly to improved and diversified diets.

Pellegrini and Tasciotti (2014) assessed the impact of crop diversification on households' dietary diversity in eight developing countries. In all the countries studied there was a positive relationship between the number of crops produced by rural households and the food groups consumed. Hence, crop diversification is an important determinant of improved diet quality. Variables such as level of education, age of the head of the household, share of female members in the family, per capita expenditure, land size, and household size increased the probability of having a more diverse diet. Irrigation variables were not included in this study.

Irrigation, Increased Food Availability, and Improved Diets

Irrigation can improve the amount of food available to the household through two main channels. The amount and diversity of home grown food can improve as a result of having access to irrigation water, and households may be able to purchase more food as a result of having more income from the sale of irrigated products. Most of the studies included in the review (21 out of 27) include some measure of food security and/or dietary intake indicators (Table 4.1). The high number of studies falling into this category is not surprising because this was one of the main inclusion criteria for the review. However, only 11 of the studies selected focused primarily on food security and nutrition outcomes (Table 3.1). The other studies aimed at analyzing the impact of irrigation on well-being or other socioeconomic aspects, and food security was only one of several outcomes studied. These more general studies present, for the most part, only broad measures of food (in)security, such as the number of days or months households are unable to meet household food needs (Adeoti et al. 2007; Bagson and Wuleka Kuuder 2013; FAO 2000; Namara, Upadhyay, and Nagar 2005; Njuki et al. 2014; Peter 2011).

The studies with a stronger food security or nutrition focus generally provide more comprehensive indicators of food consumption and dietary adequacy, including information on food expenditures, daily caloric intake, or dietary diversity measures (Benefice and Simondon 1993; Dillon 2008; Ersado 2005; Kirogo, Kogi-Makau, and Muroki 2007; Namara et al. 2011; Olney et al. 2009; Steiner-Asiedu et al. 2012; Von Braun, Puetz, and Webb 1989).

The studies reviewed generally show that irrigation adoption leads to increased and improved diets. However, most of the studies do not specify whether the improvement of the diets arises from more home grown food available or from an increase of marketable surplus leading to more food being purchased by the household. In the Sudano–Sahel region, Burney et al. (2010) analyzed the food security situation of beneficiaries of solar-powered drip irrigation systems installed in communal gardens. The consumption of vegetables during the dry season increased among program beneficiaries, and irrigators were 17 percent less likely to feel chronically food insecure one year after the implementation of the project.

Mangisoni (2008) analyzed the impact of treadle pump adoption on the food security situation of adopters and nonadopters in Malawi. In this study, *food security* was defined as having enough food to last until the next harvest (May) of every year. More than 70 percent of the households stated that they were food insecure before the installation of the treadle pumps; after adoption of the new technology only 9 percent of the households reported experiencing food insecurity. Food security was also analyzed in the same study by comparing the maize deficit—defined as less than 270 kilograms of maize equivalent per year per capita—of treadle pump users and nonusers. Maize deficit was detected in only 9 percent of the users, compared to 60 percent of the nonusers. Also in Malawi, Nkhata (2014), after controlling for selection bias, estimated the daily per capita caloric intake of rice and maize for irrigators and

nonirrigators. The daily per capita caloric intake was on average 103 calories, or 10 percent, higher among irrigators.

Several studies use household food expenditures and the percentage of household expenditure devoted to food as indicators of food security. Von Braun, Puetz, and Webb (1989) assessed the links among production, income, consumption, and nutrition in rice irrigation projects in the Gambia. The cultivation of rice increased the real income of farmers by 13 percent. The study also concluded that an additional 10 percent in annual income led to a 9.4 percent increase in food expenditures and a 4.8 percent increase in calorie consumption. Sinyolo, Mudhara, and Wale (2014) also report significant differences in food and nonfood consumption expenditures between irrigators and nonirrigators. Irrigators spent about 25 percent more on food than nonirrigators.

More complex measures of food security and nutrition, such as daily caloric intake, dietary diversity indicators, and weighed food records, are used in only eight of the studies reviewed (Benefice and Simondon 1993; Dillon 2008; Kirogo, Kogi-Makau, and Muroki 2007; Namara, Upadhyay, and Nagar 2005; Njuki et al. 2014; Olney et al. 2009; Steiner-Asiedu et al. 2012; Von Braun, Puetz, and Webb 1989), all of which had assessment of nutrition outcomes as a primary objective. Household dietary diversity is a useful indicator of the economic ability of households to access a variety of foods, while individual dietary diversity scores, usually used for children and women, are good indicators of nutritional adequacy (FAO 2010). Household dietary diversity is analyzed in Namara et al. (2011) and Olney et al. (2009), while individual dietary diversity is analyzed in Olney et al. (2009) and Kirogo, Kogi-Makau, and Muroki (2007). The evaluation of the impact of the Hellen Keller International homestead food production program on household and child nutrition conducted by Olney et al. (2009) in Cambodia is the only study that includes both household and individual dietary diversity measures. The authors conclude that in comparison to the control group, the program increased household consumption of micronutrient-rich foods such as dark green leafy vegetables and yellow or orange fruits, and maternal and child intake of some of these foods (for example, eggs and dark green leafy vegetables). Following the implementation of the homestead food production program, household dietary diversity scores had also increased more in the intervention group than in the control group. Similarly, Dillon (2008) compared the daily caloric intake of households with and without access to canal irrigation in Mali. Households with access to irrigation increased their daily caloric intake by 1,836 calories, while those without irrigation decreased their daily caloric intake by 925 calories between 1998 and 2006.

Some of the studies selected for review also report mixed or inconclusive results in terms of the impact of irrigation on food security and nutrition. Namara et al. (2011) compared the Household Dietary Diversity Score (HDDS) of farmers practicing rainfed agriculture with that of farmers practicing groundwater irrigation in Ghana. Farmers were asked about the household consumption of a set of 12 food groups during the 24-hour period prior to the interview. Nonsignificant differences between rainfed farmers (6.3) and irrigated farmers (6.5) were found. Remarkably, the farmers using permanent shallow-well irrigation had the lowest HDDS.

Benefice and Simondon (1993) also present mixed results with regard to the positive contribution of irrigation to food security and nutrition outcomes. They compared quantities of food consumed in the Senegal River Valley before and after the introduction of a modern irrigation system in 1989 by using weighed food records. Between 1957 and 1991 consumption of rice and vegetables, the main irrigated crops, increased, as did intake of vitamin A, C, and B_3. However, consumption of fish, meat, and fresh milk decreased, along with intake of calcium, vitamin B_2, and iron.

The installation of irrigation systems sometimes leads to monocropping, and in this case, irrigation may have negative impacts on nutrition. According to Hossain, Naher, and Shahabuddin (2005), who used secondary data in their analysis, an increase in rice production resulting from investments in small-scale irrigation in Bangladesh led to increased rice intake and reduced dietary diversity among the poorest households.

Irrigation systems can also improve the intake of animal-source foods as a result of higher revenues and improved livestock productivity. Livestock and other small animals can use water from irrigation systems for drinking and bathing (Meinzen-Dick 1997). Irrigation can also increase the amount

of feed available for livestock in the dry season and, as a result, expenditures on forage may decrease. For example, irrigation water can be used to produce irrigated fodder. In Africa, 14 percent of the irrigated land is used to grow irrigated fodder, mostly in Egypt, Sudan, and other parts of the northern and southern regions (Frenken 2005). Irrigated fodder production can help increase livestock and dairy productivity and, consequently, lead to increased consumption of animal-source foods. Animal-source foods have important nutritional benefits, as they are important sources of vitamin A, iron, vitamin B_2, calcium, zinc, and vitamin B_{12}, all important for young children (Murphy and Allen 2003). Livestock are also an important asset against income shocks, such as crop failures resulting from natural disasters.

Fodder irrigation was not practiced in any of the irrigation projects reviewed, but 14 of the papers selected included some sort of information on the relationship between irrigation and livestock productivity. In Tigray (Ethiopia) income gains from livestock were 14 percent higher among irrigation users compared to nonusers, suggesting that irrigation had a positive impact on livestock productivity (Aseyehegn, Yirga, and Rajan 2012). Dillon (2008) also found positive impacts of irrigation on livestock accumulation in northern Mali. Using propensity score matching methods, irrigation was found to increase livestock holdings by 5.8 to 6.4 total livestock units. The study also showed that protein consumption increased significantly among irrigators between 1997/1998 and 2006, which presumably could be attributed to higher incomes and larger livestock holdings. The difference-in-differences test estimates 77.6 grams of additional household daily protein intake for households with irrigation. Remarkably, protein intake decreased among nonirrigators.

Other studies, such as Olney et al. (2009), Namara et al. (2011), and Sinyolo, Mudhara, and Wale (2014), did not find any significant impact of irrigation on livestock production. Only Olney et al. assessed the impact of a homestead production program on the intake of animal-source foods, but no significant improvements between control and intervention households were found. Only egg consumption by children and mothers increased when compared to control households.

Irrigation systems (canals, ponds, dams) can also provide habitats for fish, crustaceans, and mollusks (Meinzen-Dick 1997), which can be important sources of micronutrients for some communities. Despite the high nutritional value of fish, little attention was devoted to fish production and consumption in the studies reviewed.

From Food Consumption to Nutritional and Health Returns

A more varied diet is usually associated with positive effects on birth weight, child anthropometric status, and hemoglobin concentrations (Hoddinott and Yohannes 2002). While several studies present evidence that irrigation leads to increased and improved diets, evidence about the linkage between irrigation and the nutritional status of individuals remains limited, as few studies collected data on these indicators. Of the 27 studies reviewed, only 7 collected anthropometric data to assess the nutritional status of children; 2 also collected data for the mothers (Von Braun, Puetz, and Webb 1989; Olney et al 2009). Information on health outcomes is also limited. Seven studies present data on morbidity-related indicators such as health expenditures or incidence of disease, and only 3 studies present clinical data, essentially anemia prevalence.

Olney et al. (2009) showed that having an improved home garden led to increased production and consumption of micronutrient-rich foods in Cambodia. However, the study found no evidence of program impact on child and maternal anthropometrics or anemia prevalence, and therefore the authors concluded that "the relationship broke down in the link between child and maternal diversity scores and health and nutrition outcomes." Nevertheless, other positive effects on health were documented. A lower prevalence of fever among children from intervention households in the two weeks prior to the survey was reported during the endline survey.

Kirogo, Kogi-Makau, and Muroki (2007) compared the nutritional and anthropometric status of children under five from households with and without irrigation in Kenya. The prevalence of stunting and underweight was higher among children from households without irrigation, although differences were not significant. Significantly higher HAZ (height-for-age Z-score) was estimated among higher-income

households with irrigation, and significantly higher WAZ (weight-for-age Z-score) was estimated among commercial households with irrigation in comparison to equivalent groups without irrigation. These results suggest that enhanced food production as a result of irrigation leads to higher food availability and improved nutritional status, but results are not conclusive.

Steiner-Asiedu et al. (2012) also analyzed the impact of irrigation on child nutritional status one and two years after irrigation was introduced in the Sissala West District of Ghana. Irrigation did not appear to have a positive effect on the nutritional status of children. According to the dietary intake records, most children (95.9 percent), from both control and interventions groups, did not meet their minimum energy requirements. Severe wasting was affecting 11, 21, and 12 percent of children in the control, one-year intervention, and two-year intervention communities, respectively, while severe underweight affected 9, 19, and 9 percent of the children in the control, one-year intervention, and two-year intervention communities, respectively. Overall, lower incidence of wasting and underweight was found in the control communities. The authors attribute these results partially to the fact that after the construction of the dam, the involvement of women in farm activities and the time spent outside the house increased, to the detriment of childcare. However, the authors also note that the control communities had mothers with more education than the intervention communities, which could also explain the higher nutritional status of children in control communities.

A seasonal comparison of the nutritional status of children and their mothers in areas with and without irrigation was conducted in the Gambia. Von Braun, Puetz, and Webb (1989) collected anthropometric data of children under ten and their mothers during the dry and wet seasons in 1985/1986. Cause-and-effect relationships between the project and the nutritional status of children were again difficult to establish. Higher levels of stunting and wasting were found in the group of children without access to irrigation. However, underweight prevalence was higher among the group of children with access to irrigation. Seasonally, prevalence of undernutrition was higher in the wet season, when food supplies are lower; this effect was more significant for wasting, as weight-for-height values reflect the short-term (acute) nutritional situation. In line with these results, weight fluctuations between the wet and dry season were smaller among women who benefited from irrigation, suggesting that seasonal imbalances between energy intake and energy expenditure were also smaller among these women. Besides lack of food, in a multivariate analysis unclean water and infectious diseases were identified as important determinants of undernutrition. High prevalence of diarrhea was associated with lower height-for-age and weight-for-age; however, the relationship was not significant for weight-for-height. The authors concluded that the prevalence of diarrhea was probably an indicator of unhygienic conditions in the home, with important effects on the long-term (chronic) nutritional situation.

Benefice and Simondon (1993) measured HAZ, WAZ, and WHZ (weight-for-height Z-score) outcomes three times at six-month intervals among 315 children after the introduction of flood irrigation in the Middle Valley of Senegal. No variation in the prevalence of undernutrition measured as HAZ, WAZ, and WHZ was observed from one visit to another. The authors also compared anthropometric data collected in 1983 with data collected in 1991 after the intervention. No significant differences in the prevalence of wasting were encountered among children under five. However, thinness among children of five to ten years and among adults had been reduced. The authors attributed the lack of improvement in anthropometric indicators among small children to the lower progress made in Senegal in water supply and sanitation as compared to food production improvements. They argued that older children are better protected against infections associated with lack of adequate water and sanitation and, therefore, improvements in food consumption are more likely to translate into a better nutrition status in that group (for example, lower prevalence of wasting).

A negative effect of small-scale irrigation on health was reported in northern Ethiopia (Ersado 2005). The number of days male and female adults spent sick in intervention villages was significantly higher than in control villages, mostly due to a higher incidence of malaria. More labor time was also lost in intervention villages due to sickness. Women spent three times as much time at home taking care of sick family members in villages near a microdam than in control areas.

In contrast, irrigation may favor higher investments in healthcare, education, water, and sanitation as a result of higher incomes. However, current evidence of this linkage is scarce or inconclusive. For example, Burney et al. (2010) found nonsignificant changes in healthcare expenditures for irrigators compared to nonirrigators. Additionally, Aseyenhegn, Yirga, and Rajan (2012), by comparing several features of irrigation users and nonusers, concluded that healthy households are more likely to adopt irrigation technologies in Tigray, Ethiopia. By extension, we could assume that Ethiopian households with irrigation were presumably healthier than households without irrigation.

Multiple Use of Irrigation Water, WASH, and Better Nutrition and Health

Irrigation water may be used for different domestic purposes such as drinking, washing, bathing, and hygiene or for other productive purposes such as livestock rearing, aquatic production, or small businesses (Meinzen-Dick 1997). Sometimes the multiple uses of irrigation water emerge in an unplanned way, but other times multiple-use considerations are incorporated into the design of irrigation systems in order to fulfill users' needs and avoid damage to the system or conflicting situations (Renault, Wahaj, and Smits 2013; van Koppen et al. 2009).

Due to the multiple uses of irrigation water, irrigation programs can sometimes lead to improved WASH (water, sanitation, and hygiene) in communities suffering from lack of access to adequate water supply and sanitation. An example of this is found in the Bwanje Valley Irrigation Scheme in Malawi. As part of the irrigation program, 13 boreholes for domestic use were constructed in the intervention communities (Nkhata 2014). Another example of a multiple-use irrigation system can be found in Pakistan, in van der Hoek, Feenstra, and Konradsen (2002).

The nutritional status of children depends not only on food consumption and dietary adequacy but on other factors such as water supply and sanitation and incidence of disease (Benefice and Simondon 1993; Von Braun, Puetz, and Webb 1989). The results of a meta-analysis conducted in a recent Cochrane Review point at a slight but statistically significant effect of WASH interventions on HAZ in children under five years of age (Dangour et al. 2013). Despite these indications, very few rigorous trials have evaluated the effect of WASH on nutrition outcomes (see Dangour et al. 2013).

Diarrhea, nematode infections, and environmental enteropathy are the main pathways from poor WASH to child undernutrition (Dangour et al. 2013). Diarrhea and nematode infections have typically been considered important causes of severe undernutrition, but environmental enteropathy has only recently started to receive more attention as an important underestimated determinant of undernutrition (Lin et al. 2013; Spears, Ghosh, and Cumming 2013; Humphrey 2009). Chambers and Von Medeazza (2013) argue that the role of environmental enteropathy as a driver of undernutrition may be greater than diarrhea. Environmental enteropathy is a subclinical disorder of the small intestine caused by lack of access to adequate sanitation and poor hygiene conditions. Environmental enteropathy damages the wall of the small intestine and the intestinal villi and, as a result, the area and the capacity to absorb nutrients is reduced. In addition, energy and nutrients are diverted from growth to the immune system in order to fight the infection (Korpe and Petri 2012). The reduced visibility of environmental enteropathy and the fact that this disorder is far more difficult to test for than diarrhea have contributed to the underappreciation of this illness in nutrition-related research.

Despite its relevance for nutrition and health, only eight studies included in the review documented to some extent the WASH situation of the households using irrigated agriculture, and among those that did so, most collected little information on the topic. Only one of the studies systematically assessed the effect of irrigation on the WASH and health condition of the intervention households (Van der Hoek, Feenstra, and Konradsen 2002). The authors concluded that greater water availability for domestic purposes as a result of irrigation adoption was associated with a lower prevalence of diarrhea and stunting among Pakistani children. Von Braun, Puetz, and Webb (1989) also showed in a mulitvariate analysis that lower water quality was associated with higher levels of stunting among children in the Gambia.

Irrigation and Other Health-Related Considerations

Although irrigation interventions can have many positive effects on health, some potential negative effects also need to be examined. Irrigation schemes may alter vector-breeding habitats and, as a result, the risk of vector-borne diseases such as malaria, dengue, and schistosomiasis may change too. Among the studies selected for review, only Ersado (2005) measured the effect of irrigation on the prevalence of water-borne diseases. Ersado analyzed the impact of microdam construction on malaria and schistosomiasis incidence in Tigray (Ethiopia). Malaria incidence was significantly higher in intervention villages—32 percent among households in microdam villages, compared to 19 percent in control villages. Remarkably, and in spite of the higher incidence of water-borne diseases and associated higher health expenditures and time lost being sick in intervention areas, the authors concluded that the marginal benefit of the investment in irrigation offset the costs.

Several other studies analyze the effect of irrigation systems on vector-borne diseases (see literature reviews from Ijumba and Lindsay 2001; Keiser et al. 2005), and the results depict a complex picture. The effect of irrigation on the incidence of vector-borne diseases depends on multiple factors, such as the epidemiologic setting, the ecology of the area, and the socioeconomic status of the population (Keiser et al. 2005; Wielgosz et al. 2012). Keiser et al. (2005) analyzed the results of 11 studies conducted in irrigation areas of stable malaria transmission in Africa. None of the studies found evidence of increased prevalence of malaria in irrigated villages as compared with nonirrigated villages. A lower incidence of malaria was even reported in some of the studies; this lower incidence was attributed to improved socioeconomic status, effective vector-control programs, and changes in health-related behavior. Another explanation for the lower incidence of malaria in certain contexts was found in the use of insecticide-treated nets and the differing presence of cattle in irrigated villages. Unprotected cattle seemed to attract mosquitos diverted by insecticide-treated nets. However, a greater risk of malaria incidence was found in irrigation villages with unstable malaria prevalence, where people have little or no immunity to malaria parasites (Keiser et al. 2005). Similarly, Ijumba, and Lindsay (2001) concluded that irrigation systems do not seem to increase malaria risk in Africa, with the exception of areas of unstable transmission.

Negative outcomes of irrigation on health may also result from the increased use of complementary inputs, such as pesticides, fertilizers, and other chemical products, due to the higher input intensity of irrigated agriculture. Pesticides may cause acute poisoning through intentional or accidental exposure and through long-term exposure—for instance, through the ingestion of pesticide residues on food or in drinking water. Human poisoning by pesticides is becoming a growing concern in developing countries, where the use of pesticides is mostly unregulated and where handling practices are often inadequate or unsafe. The most reported health problems associated with pesticide exposure include neurological abnormalities; respiratory diseases; and reproductive, endocrinological, and dermal problems (Kesavachandran et al. 2009). Successful capacity building in safe pesticide management remains an important area for action research in Africa south of the Sahara. The World Health Organization (WHO 1990, quoted in Eddleston et al. 2002) estimated that every year, three million people are poisoned by pesticides, causing 220,000 deaths worldwide, including many suicides.

The number of studies analyzing the effect of irrigation adoption on pesticide use and associated health impacts remains limited. Only one of the studies included in the review examined these linkages. Clarke et al. (1997) researched the prevalence of symptoms associated with organophosphorus pesticides and carbamates among irrigation workers in Ghana. The study revealed that the three symptoms of headache, blurred vision, and nausea/vomiting were significantly higher (at 5 percent significance level) among irrigators as compared with a control group of teachers, which suggests that farm laborers and owners of irrigated lands are more likely to be exposed to harmful chemicals. The level of cholinesterase was significantly lower in the subjects exposed to pesticides than in controls, indicating a lower activity of the enzyme acetylcholinesterase. Organophosphorus pesticides and carbamates inhibit the enzyme acetylcholinesterase at nerve endings (Clarke et al. 1997).

The use of groundwater naturally contaminated with arsenic for irrigation purposes poses another potential risk for human health. Bangladesh is the country most affected by arsenic contamination, though high levels of arsenic in groundwater have also been reported in other countries, such as China, India, Nepal, Thailand, Argentina, and Chile. Several studies have shown that the use of arsenic-contaminated water for irrigation can lead to arsenic accumulation in the soil and successive contamination of crops, which can pose a threat to human health and long-term loss of yields. Rice crops are prone to arsenic contamination because their cultivation demands high volumes of water and flooded conditions. A review study by Heikens (2006) concluded that none of the existing toxicity data represent field conditions sufficiently well. It also noted that a better understanding of the relationship between arsenic in the soil and its uptake and toxicity is needed.

Wastewater from urban and peri-urban areas is increasingly used for irrigation purposes in water-scarce regions. Although wastewater provides important nutrients for soils and plant growth, it can also contain heavy metals and pathogens that can be harmful to soils and crops irrigated with wastewater. Furthermore, wastewater is often used without taking appropriate precautions to diminish health and environmental risks (Jawahar and Ringler 2009). It has been estimated that around 20 million hectares are irrigated with wastewater, mainly in Asia, Europe, South America, and the United States, and about 10 percent of the world's population could be consuming foods produced with wastewater (van der Hoek 2004, quoted in Srinivasan and Reddy 2009; Hamilton et al. 2007, quoted in Srinivasan and Reddy 2009; WHO 2006, quoted in Srinivasan and Reddy 2009). Srinivasan and Reddy (2009) compared the morbidity rates of six villages that used wastewater for irrigation with one control village irrigated with normal-quality water in the peri-urban areas of Hyderabad, India. Higher rates of morbidity, especially among females, were observed in the villages using wastewater as an irrigation source. The costs of illness, including direct and indirect costs, were also analyzed, but no statistically significant differences were found between control and wastewater-irrigating villages.

The Gender Implications of Irrigation

Women play a significant role in the agricultural sector (Quisumbing et al. 2014). However, women often have limited access to land, water, labor, capital, technology, information, and other assets (Molden 2007; Goh 2012). The gender of the person who has control over and access to assets has important implications for health and nutrition outcomes because men and women usually have different preferences about how to allocate resources. For instance, women tend to invest more in household nutrition, education, and health (Meinzen-Dick et al. 2012). In addition, women are usually responsible for food preparation and childcare. Thus, empowering women can make an important contribution to improved food security and child nutrition (Quisumbing et al. 1995; Smith et al. 2003; Malapit et al. 2013; Sraboni et al. 2014).

According to van Koppen (2002), the impact of irrigation interventions on women's empowerment largely depends on whether women are farm decisionmakers or simply family laborers. In other words, if women mobilize inputs themselves and are included in irrigation institutions, they are more likely to benefit from irrigation interventions. With this in mind, van Koppen developed a gender performance indicator for irrigation to analyze the presence or absence of gender-based differences in collectively managed schemes. Three main aspects are part of the indicator: who the farm decisionmakers are (males, females, mixed), participation in forums (such as water associations), and share in leadership positions.

Another indicator that could potentially be used to measure the effect of irrigation interventions on gender is the Women's Empowerment in Agriculture Index (WEAI), developed by the United States Agency for International Development (USAID), IFPRI, and the Oxford Poverty and Human Development Initiative (OPHI). This indicator comprises two subindexes—five domains of empowerment (5DE) and a gender parity index (GPI), the latter of which reflects the percentage of women who are as empowered as the men in their households. The 5DE tailored to the case of irrigation could be (USAID, IFPRI, and OPHI 2012):

- **Production**: Decisions about irrigated production
- **Resources**: Access to and decisionmaking power about productive resources and assets, such as land, agricultural inputs, or credit
- **Income**: Control of irrigated outputs and expenditures
- **Leadership**: Involvement in water users' associations and other social or economic groups
- **Time**: Allocation of time to irrigated agriculture and domestic tasks

Although the WEAI has not yet been used to evaluate the impact of irrigation on women's empowerment, the Innovation Lab on Small-Scale Irrigation (ILSSI) project will use this tool to evaluate key gender differences in irrigated agriculture (http://borlaug.tamu.edu/projects-by-region/sub-saharan-africa/feed-the-future-innovation-lab-for-small-scale-irrigation/).

Of the 27 studies selected for review, 12 discuss to some extent the gender implications of irrigation and the main roles of women in irrigated agriculture; however, only 4 papers have gender analysis as the main goal. Van den Bold et al. (2013) study the impact of a homestead food production program on the ownership, use, and control of men's and women's assets in Burkina Faso. The program primarily targets women, with the aim of reducing child undernutrition. After the program, men continued to own most of the land, but the number of agricultural assets and small animals owned by women had increased significantly in intervention villages compared to control villages. Women were also the main decisionmakers regarding the crops grown in the home garden and the chickens reared. The revenue generated from the sales of these products was also controlled by women and, therefore, greater availability and intake of food within the household and improved child nutrition were expected.

In Ethiopia, male-headed households were 38 percent more likely to participate in irrigation activities than female-headed households, because the latter had lower income and faced a shortage of labor and market information. Consequently, women frequently ended up renting or sharing out their land (Aseyehegn, Yirga, and Rajan 2012). Similarly, in Ghana, female-headed households were also found to adopt water-lifting technologies less frequently than male-headed households. However, these differences were not so acute for canal irrigation, most likely due to the fact that local regulations require that farmer groups allocate irrigated land to women in public schemes (Namara et al. 2014).

Securing women's land rights can favor adoption of irrigation technologies by women, as shown in van Koppen, Hope, and Colenbrander (2012). Land ownership was an important determinant of irrigation adoption among female-headed households in Zambia and Ghana (van Koppen, Hope, and Colenbrander 2012). Lower access to cash and information about irrigation technologies was another important constraint for women's participation in irrigation in Kenya and Tanzania. In a qualitative study about women's access to and ownership of KickStart pumps in Kenya and Tanzania, women were found to purchase less than 10 percent of the pumps (6 percent in Tanzania and 18 percent in Kenya) because of unequal access to information about the pumps and financial constraints (Njuki et al. 2014).

The same study showed that in some areas the use of manual pumps, in particular pedaling the pump, is considered culturally inappropriate for women. Some women also reported that manual pumps were hard to operate. Finally, the study analyzed women's decisionmaking power over crop choices and control over income from irrigated crops. Decisions related to high-income crops were usually made by men, while women had more autonomy on crops for home consumption, such as leafy vegetables. Men preferred planting cash crops (for example, tomatoes) because these can be sold in bulk for cash, while women preferred planting leafy vegetables such as kale, spinach, and amaranth because these crops can be used for home consumption and can also be sold regularly in small quantities near the homestead. Women usually had control over income from the sale of these crops.

Empowering women through irrigation can be an important pathway for improving household nutrition, as shown in Burney et al. (2010). The authors evaluated the contribution to food security of an irrigation project targeting women's agricultural groups. Women participating in the project kept 18 percent (8.8 kilograms per month) of the food grown and sold the rest in the local market. Their standard of living increased as compared to nonirrigator women—their consumption of vegetables reached the U.S. Department of Agriculture's recommended daily allowance, and additional income was used to purchase staples and protein for household consumption during the dry season.

Irrigation interventions can also change farmers' time use with positive as well as negative trade-offs for women, which will largely depend on the local context. A study about smallholder irrigation schemes in Zimbabwe conducted by FAO (2000) concluded that women provided the bulk of the labor required on surface irrigation systems. Similarly, Upadhyay, Samad, and Giordano (2005) found that women using micro-irrigation technologies in Nepal spent significantly more time producing vegetables than their male counterparts, who only contributed 12 percent of the time. If women have control over the income and the food generated from irrigation activities, chances are high that the diets of children and the rest of the family will improve. However, an increase in women's agricultural workload may also have a negative impact on the amount of time women can devote to caregiving activities, and in that case irrigation can presumably have a negative effect on child nutrition and health (Von Braun, Puetz, and Webb 1989; Steiner-Asiedu et al. 2012). Some of the negative impacts of irrigation on child nutrition and health could be minimized, for example, by providing childcare services in irrigation areas, as suggested by Von Braun, Puetz, and Webb (1989). Lastly, irrigation can also reduce the time women spend fetching water for domestic and livestock uses and therefore allow more time for other activities such as income-generating, caregiving, or social activities (Upadhyay, Samad, and Giordano 2005; Njuki et al. 2014).

5. HOW TO DESIGN NUTRITION-SENSITIVE IRRIGATION INTERVENTIONS

In most of the papers reviewed, irrigation seemed to contribute to improved food security, but the positive impact of irrigation interventions on nutrition outcomes was seldom established, most likely because insufficient attention was given to nutrition goals during the design of the irrigation interventions. Poverty reduction and productivity gains are usually the most important drivers of irrigation programs, but with the exception of homestead production programs, most of the irrigation programs evaluated in the papers reviewed did not have nutrition improvement as an explicit goal. Incorporating nutritional, health, and gender considerations into the design of new irrigation programs and policies would be an important step toward realizing the full potential of irrigation interventions.

Beneficiaries of irrigation programs often receive training on how to operate and maintain irrigation systems, but nutrition aspects are rarely considered. Adding food and nutrition education components to these training programs, such as recommendations on which crops to plant to improve child nutrition and how to better preserve and cook irrigated crops, would help reinforce the pathway from improved agricultural productivity to better nutrition and health.

More guidance and support to minimize the increased risk of infection with water-borne diseases such as malaria and schistosomiasis would also pay off in terms of health gains. Awareness campaigns to promote safe practices near irrigation areas, such as the use of insecticide-treated bed nets, would help minimize the risk of malaria infection. In addition, healthcare centers in communities near irrigation schemes, in particular in areas with unstable malaria transmission, should be adequately equipped to deal with the potential increase in water-borne diseases (Ijumba and Lindsay 2001).

Specific policies that promote multiple uses of irrigation water can also be instrumental in improving nutrition and health outcomes. Recent evidence points to a lack of water supply and sanitation and associated environmental enteropathy as underestimated factors influencing the nutritional and health status of children. Therefore, adding a water supply component to the design of irrigation interventions can be beneficial for child nutrition and health. Irrigation water is also sometimes used as drinking water for livestock and for aquatic production or for irrigated fodder production. Linking irrigation projects to livestock and/or fish production can also have important nutritional benefits, as consumption of animal-source foods has been shown to significantly improve child nutritional status (Hoddinott, Headey, and Dereje 2014; Rawlins et al. 2014). In brief, the positive effects of irrigation interventions on nutrition and health outcomes could be multiplied with better integration of different sectors of activity such as agriculture, water supply and sanitation, health, and education.

Finally, it is also critical to integrate gender considerations into policy design in order to favor women's involvement in irrigated agriculture. Instead of designing "gender blind" irrigation programs (like many of the programs reviewed in this paper), program designers should incorporate specific provisions to target and empower women. Men generally have better access to irrigation technologies and own most irrigation assets (Njuki et al. 2014). As a result, the income generated from irrigated agriculture is usually controlled by men and spent according to their preferences. Women tend to invest more in household nutrition and health and, therefore, improving women's access to and ownership of irrigation technologies and control over irrigated produce can have a positive effect on nutrition and health outcomes. Securing women's land rights and improving women's access to credit and information are also critical steps in promoting women's access to irrigation pumps and other irrigation technologies. Lastly, it is also important to design irrigation components such as manual pumps according to women's needs and local cultural norms.

6. CONCLUSION

Irrigation interventions can improve nutritional outcomes through multiple pathways, including increased productivity and availability of food supplies and improved diets (in quantity and quality). However, the pathways linking nutritional and health gains with irrigation remain understudied. Most of the studies included in the review showed a positive effect of irrigation interventions on food security. However, results regarding the relationship between irrigation, nutrition, health, and gender outcomes were inconclusive, which is partially attributed to the fact that few studies include comprehensive measures of these outcomes. For example, few studies present data on dietary diversity, anthropometrics, morbidity, and clinical indicators. Ruel and Alderman (2013) also drew attention to the lack of clear evidence regarding the linkage between agricultural interventions and nutrition and health aspects, mainly due to the lack of rigorous empirical studies.

Many of the studies included in the review contained some methodological flaws worthy of note. In some cases, small samples did not allow for firm conclusions to be drawn. Self-selection bias and lack of comparable controls were also limitations in several studies. However, it seems difficult to avoid the self-selection problem in irrigation evaluations because randomization of the beneficiary households is often not feasible in irrigation interventions. Some studies tried to solve the problem with the use propensity score matching methods. Finally, most studies did not collect panel data and therefore were unable to control for unobservable effects. All in all, we conclude that more rigorous evaluations of the impact of irrigation interventions on nutrition outcomes are needed. Developing such evidence will be important for the successful implementation of new irrigation projects, especially in Africa south of the Sahara, where the potential to expand irrigation is large and where recent projections indicate that childhood undernutrition levels will continue to grow over the next two decades.

Six main aspects should be considered when designing more nutrition-sensitive irrigation interventions: (1) food security and nutrition gains should be stated goals of irrigation programs; (2) training programs and awareness campaigns should accompany irrigation interventions to promote nutrient-dense food production and consumption as well as minimization of health risks; (3) multiple uses of irrigation water should be recognized in order to improve access to water supply and sanitation and livestock and aquatic production; (4) women's empowerment and women's participation in irrigation programs should be promoted; (5) homestead food production should be encouraged; and (6) policy synergies between different sectors (agriculture, nutrition, health, water supply and sanitation, education) should be sought.

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