

Global Change and Investments in Smallholder Irrigation for Food and Nutrition Security in Sub-Saharan Africa



Munir A. Hanjra and Timothy O. Williams

Abstract Investments in irrigation contribute to poverty reduction and enhance food security. This paper considers irrigation investments more broadly in the context of **rural–urban linkages** and thus examines rural irrigation schemes and peri-urban and urban agriculture using freshwater, groundwater and wastewater. We present case studies from East, West and Southern Africa, while focusing on the imperative of smallholders and of food security and nutrition. Evidence from Big Data and telecoupling show that, amid global change and sustainability issues, irrigation development strengthens connections between humans and nature with notable benefits to food security. **Transforming investments** to feed the future generation require priority investments in irrigation, solar energy for groundwater pumping, groundwater development policy, and integration of peri-urban and urban agriculture into food systems. Equally important will be **no-regret interventions** in wastewater reuse, water storage and groundwater buffer, micro-irrigation, and wholesale reconfiguration of farming systems, through anticipatory investments, to safeguard food security and sustainability into the distant future.

1 Introduction

Food security and agriculture are top development priorities across Sub-Saharan Africa (SSA). The Sustainable Development Goals (SDGs) aim to end poverty, end hunger, enhance food security and nutrition, and double agricultural production for smallholders. The EU Agenda for Change and the African Union prioritise sustainable agriculture and smallholder irrigation as a strategy for poverty reduction in Africa. Agricultural transformation and the doubling of irrigated area is a key pillar

We are indebted to Munir Hanjra who contributed to this book prior to his death in April 2019.

M. A. Hanjra (Deceased)
International Water Management Institute (IWMI), Pretoria, South Africa

T. O. Williams (✉)
International Water Management Institute (IWMI), Accra, Ghana
e-mail: wiltmt@aol.com

of the Comprehensive Africa Agricultural Development Programme (CAADP) and Feed Africa Strategy (AfDB 2016). Irrigation is in the manifesto of many political parties across the Southern African Development Community (SADC). National policies support new irrigation investments in agricultural greenbelts and growth corridors in Malawi and Tanzania. World Bank (2008) and other donors have renewed calls for re-engaging in agricultural water management solutions to achieve water security for sustainable development (Grey and Sadoff 2007; Sadoff et al. 2015).

Public policies and investments are needed today to ensure sustainable food security—defined as sustained poverty reduction and access to nutritious and healthy food for all (Hanjra et al. 2017c). Investments in sustainable intensification of agriculture are required for human prosperity and global sustainability (Conceição et al. 2016; Rockström et al. 2016; Hanjra et al. 2017e). Investments in irrigation can contribute to poverty reduction and enhance food security through several impact pathways, including higher crop yield, higher food production, higher income and consumption, gains in employment, higher wage earnings, women’s empowerment through female employment, lower food prices, year-round food availability, augmentation of household assets, public infrastructure, education and health, and greater human prosperity (Hussain and Hanjra 2004; Hanjra and Gichuki 2008). Irrigation also improves crop diversification and market access, which together have positive effects on dietary diversity. Investment in irrigation improves food security and reduces poverty—there is robust evidence from Asia (Hussain and Hanjra 2003, 2004; Shinkai et al. 2007; Fan et al. 2008; Pingali 2012; Ward et al. 2013; Unver et al. 2016; Giordano et al. 2017) and strong emerging evidence from SSA (Hanjra et al. 2009a, b; Burney and Naylor 2012; Wichelns 2014; Williams 2015). Smallholder irrigation also improves nutrition outcomes—there is inconclusive but new evidence from Africa (Burney et al. 2010; Dillon 2011; Alaofè et al. 2016; Hanjra et al. 2017c). Also, the following nutrition impact pathways are supported by strong evidence: (i) food production, (ii) income (agricultural and non-agricultural) and (iii) female employment.

This chapter focuses on smallholder agriculture and considers irrigation more broadly within the rural–urban continuum in three sub-sectors: **rural irrigation schemes** using surface and groundwater, **peri-urban** and **urban agriculture** using wastewater and groundwater for irrigation. We aim to illustrate the contribution of smallholder-irrigated agriculture to various dimensions of food security and the overall contribution of small farms to economic growth, within the bigger picture of structural transformation and global change. In-depth case studies into public investments in irrigation in South Africa, public–private partnerships in Zimbabwe, and sustainable intensification in Tanzania are presented, along with a broader review of evidence from East, West and Southern Africa, including Big Data and telecoupling. The analysis shows what irrigation contributes to the well-being of smallholders (‘beneficiaries’), what smallholder farmers in irrigation contribute towards food security (‘agents of change’), and what policy opportunities exist to enhance food security and target nutrition. Programmatic-level support and policy interventions are needed to shape future investments in irrigation and promote related investments in appropriate farming and agrifood systems to deliver sustainable transformations, the EU Agenda for Change and the SDGs across SSA.

2 Global Change and Transformation of Smallholder Agriculture in Africa

Global food production more than doubled during the past 50 years and outpaced population growth and food demand in all regions except SSA. Global population stabilisation seems unlikely this century and world population is projected to increase from the current 7.2 to 9.6 billion in 2050 and 10.9 billion in 2100 (Gerland et al. 2014). Much of the population growth is expected to occur in Africa, where the population is projected to increase from roughly 1 billion today to between 3.1 and 5.7 billion by the end of this century. That would make Africa's population density roughly equal to that of China today, with huge policy implications for future food security and related areas—environmental (natural resources, water quality, wastewater reuse), economic (jobs, wages, poverty, inequality, rural-urban divide, migration), social (crime, unrest), health (higher maternal and child mortality), government (investments in agriculture, irrigation, health, education, energy, infrastructure, water and sanitation) and climate change (biofuels, solar power, food miles, carbon emissions).

Africa has made tremendous gains in food security during the past decades. While the outlook for 2050 and beyond is encouraging, population growth, urbanisation, natural resource distribution patterns, climate change and, above all, future changes in diets (Keats and Wiggins 2017) pose complex challenges in terms of sustainably feeding the future generation and achieving the SDGs. Urbanisation drives up the demand for food products, such as premium rice, that are not supplied by local farmers, suggesting that net negative trade will increase without transformation. However, Africa has enough labour, land, water, energy and natural resources, and African food security prospects are brighter than ever (FAO 2015). Nonetheless, investments are needed to transform farming systems across Africa (Williams 2015; Dixon et al. 2017).

Three basic transformations are needed to ensure food security: structural, agricultural and dietary transformation (Timmer 2017). Structural transformation involves four main drivers including: a declining share of agriculture in national income and employment, a rising share of urban economic activity in manufacturing and modern services, migration of rural workers to urban areas, and demographic transition towards lower birth and death rates and better health standards. Indeed, structural transformation has been the main pathway towards food security and out of poverty for many of today's developed societies; it depends on rising productivity in both agricultural and non-agricultural sectors accompanied by a declining share of agriculture in income and employment (Timmer 2017). Data from 29 developing countries confirm that structural transformation raises total income and poverty falls faster with government support for smallholder agriculture, which in turn improves nutrition in rural areas (Webb and Block 2012).

Agricultural transformation is driven by changing demand for food in domestic markets, opportunities for food exports, commercialisation, intensification and diversification of agriculture and adoption of innovations in commodity value chains

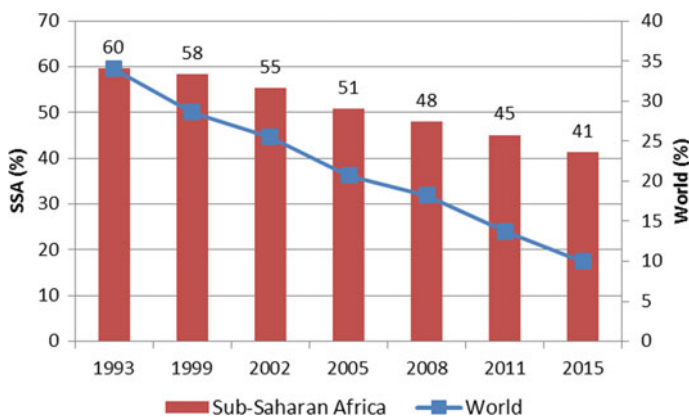


Fig. 1 Progress towards poverty reduction (below USD 1.90/day). *Data Source* World Bank

which together serve to raise productivity per ha and productivity per worker (Barrett et al. 2017; Timmer 2017). Africa shows early signs of “coupled growth”, i.e. agricultural growth and structural transformation (e.g. in Ethiopia, Rwanda) (Abro et al. 2014; Barrett et al. 2017; Sheahan and Barrett 2017). Examples of country specific transformation include tenure security and irrigation investments in Tanzania, improved rice yields in Senegal and Mali, higher cotton yield in Burkina, scaling-up of agricultural innovations in Nigeria, warehousing receipt system in Uganda, land use consolidation policy and registration system in Rwanda, floriculture exports in Ethiopia and horticulture exports in Kenya (Verdier-Chouchane and Boly 2017).

But the challenge is in bringing to scale existing and successful interventions to enhance food security and reduce poverty for millions of households across Africa (Appendix). Poverty has declined overtime in SSA (World Bank 2018) (Fig. 1), and the inclusiveness of child health improvements has increased (Sahn and Younger 2017). The number of undernourished increased from 177 million (2005) to 232 million (2017), with rapid growth in almost all sub-regions in recent years, especially in Western Africa (FAO 2019). This situation is even worse in conflict-affected countries of SSA (where undernourished people increased by 23.4 million between 2015 and 2018) and in drought-sensitive countries (where undernourished people increased by 45.6% since 2012). Thus, major investments are needed in agriculture itself to support structural transformation and governments must provide strong support to ensure food security for their citizens across Africa.

2.1 Global Change and Rural–Urban Linkages

Rapid population and income growth and greater rural–urban linkages are increasing demand for energy, food and water across Africa. Supportive developments have also taken place in regional trade liberalisation and food markets, strengthening

institutions and policies, social media, and investments in human capital and modern technology. Amid such drivers and trends, rural–urban linkages and farming systems are changing dynamically. Urbanisation pushes farmers outwards, such that many begin to farm on city outskirts to grow fresh vegetables for cities, using wastewater for irrigation (Hanjra et al. 2012). This transition transforms the role of peri-urban areas in food security. Urban areas are extending further into peri-urban and rural areas, such that urban expansion is taking arable land out of food production—resulting in about 1.8–2.4% loss of global croplands by 2030, with 85% of this taking place in Asia and Africa. The most affected countries and regions in Africa in terms of crop production loss are Egypt (36% loss), Nigeria (12% loss), and the region around Lake Victoria basin in East Africa (Bren d’Amour et al. 2016).

Urbanisation impacts the dynamics of city region food systems and the food mix demanded by urban consumers—reflecting income, cultural diversity and lifestyle (westernisation of diets—Pingali 2007)—and this, in turn, influences food production and global food supply chains (Schmidt et al. 2015). Indeed, dynamic areas around modern cities are subject to rising population pressure, with cities contributing to the uncoupling of food consumption and local agriculture and reducing capacity for food self-sufficiency (Tedesco et al. 2017). There is ample opportunity to recouple food production and consumption in urban and peri-urban agriculture through recovery and reuse of nutrients, wastewater and energy from urban sanitation systems in agriculture, but investments are needed to accomplish this (Otoo and Drechsel 2017).

2.2 *The Imperative of Smallholders and Food Security*

There are about 475 million farms in the developing world (Rapsomanikis 2015). They contribute to food security, sustainable use of natural resources, rural economies and livelihoods. Recent assessments suggest that growth in smallholder agriculture can have strong impacts on poverty reduction and food security (IFAD 2011; Lowder et al. 2016). Also, the success of rural development strategies in Africa depends on small farms (Salami et al. 2010; Wiggins et al. 2010; Larson et al. 2016).

Smallholders make a notable contribution towards food security and global food production, producing nearly half of the world’s food. Smallholder-dominated systems (<5 ha per household) in Latin America, SSA, and South and East Asia account for about 380 million farming households, 30% of agricultural land, 70% of food calorie production in these regions and more than half globally. They provide 70% of calories consumed compared with 50% globally (Leah et al. 2016). SSA has 43.55 million smallholder families (<2 ha), accounting for 80% of farms; 69% of the calories produced in smallholder systems, and 84% on farms in urban areas.

Smallholder food production within and around cities has the potential to enhance access to healthy and nutritious food; improve environmental quality by reducing urban heat island effect, emissions and storm water runoff; promote local circular economies; create new jobs in peri-urban areas; reduce dependence on expensive food imports; and support agricultural transformation that reduces poverty (Zezza

and Tasciotti 2010; Grewal and Grewal 2012). Achieving the imperative of local food security through self-reliance requires effective use of local land and water resources and investment and policy support from city authorities and governments to promote safe reuse of wastewater and nutrients in urban and peri-urban food production systems. This will support a circular metabolism model for enhanced urban resilience (Hanjra et al. 2017d).

We need the World Bank, we need the IMF, we need all the big foundations, we need all the governments to admit that for 30 years we all blew it, including me, when I was President. We blew it. We were wrong to believe that food is like some other product in international trade. And we all have to go back to a more environmentally responsible, sustainable form of agriculture. We should go back to a policy of maximum **food self-sufficiency**.

Former US President Bill Clinton, 2008.

3 Methodology and Conceptual Framework

The overall objective of this paper is to showcase what works where, and agricultural transformation pathways to enhance future food security and prosperity in Africa through renewed investments in smallholder-irrigated farming systems and supportive public policies. This is in contrast to the usual portrayal of irrigation success or failure and deep-rooted factors limiting paths to successful transformation in Africa. Our focus is on steering local change towards a brighter future outlook for shared prosperity for the people of Africa. To end poverty (SDG 1), end hunger and enhance food security and nutrition (SDG 2) in Africa, our conceptual framework no longer focuses on conventional irrigation using freshwater only, but instead presents wider options—to ensure sustainable water management and sanitation (SDG 6), sustainable energy (SDG 7) using solar power for groundwater irrigation, and sustainable production and consumption patterns (SDG 12). Thus, another major methodological departure is the broader focus on irrigation along the rural–urban continuum to link directly to realities on the ground across Africa. We chose case study data and methods to examine smallholder rural irrigation schemes and peri-urban and urban agriculture systems using surface water, groundwater, and wastewater. Rural–urban linkages and solar energy options help to provide more promising perspectives on sustainable water management solutions for enhancing food security, within the urban sanitation–agriculture interface and green energy solutions.

We present findings from studies across East, West and Southern Africa, using mixed methods. National irrigation scheme (NIS) databases for South Africa, Tanzania and Zimbabwe were used to select several irrigation schemes in each country for in-depth case studies, involving extensive field data collection missions, face-to-face interviews with irrigators and other stakeholders, workshops with irrigation authorities, panel discussions with local leadership and district authorities, regional

water policy dialogue, and presentations to donors and global experts¹ (Riesgo et al. 2016). We applied extensive data filtering to select and review recent studies published in peer-reviewed journals to illustrate the contribution of irrigation investments to food security in SSA, including the Middle East and North Africa (MENA). Our primary focus was on food and nutrition security, within the broader context of the SDGs and predicted climatic and demographic changes.

4 Results

There is widespread consensus that past investments in irrigation have enhanced food security, alleviated poverty and transformed agriculture across Asia (Fan et al. 2000, 2008; Hussain and Hanjra 2003, 2004; Kurosaki 2003; Pingali 2015; Mishra et al. 2017). However, relatively little has been published about the poverty and food security impacts of past investments in irrigation in SSA, though there is strong evidence from new studies on smallholder irrigation across Africa (Hanjra and Gichuki 2008; Hanjra et al. 2009a, b; Burney and Naylor 2012; Hagos et al. 2017; Woodhouse et al. 2017). Evidence on nutrition outcomes is, however, relatively limited (Burney et al. 2010; Dillon 2011; Alaofè et al. 2016; Hanjra et al. 2017c).

Studies from **Nigeria, Mozambique, Tanzania, Uganda** and Nepal show that agricultural production has direct and important linkages with household dietary and nutrition outcomes (Carletto et al. 2015), while data from Indonesia, **Kenya, Ethiopia, and Malawi** show that empirical evidence on the link between production and consumption diversity is weak (Sibhatu et al. 2015). Thus, the evidence on agriculture and nutrition outcomes remains inconclusive. The lack of evidence on the impact of agricultural programmes on nutrition outcomes is interpreted as a reflection of the weakness in programme design and implementation, lack of rigour in evaluation, and more importantly the fact that emphasis on irrigation/agriculture and nutrition outcomes is relatively new (Carletto et al. 2015; Pingali 2015). However, for the first time, SDG 2 has a dedicated target to ‘end all forms of malnutrition’. Programmatic support for agriculture and irrigation interventions can play a direct role in enhancing food security and nutrition, but nutrition outcomes may depend on local conditions and the state of the economy (Domènech 2015; Fiorella et al. 2016; Pandey et al. 2016). Evidence-based interventions and nutrition-sensitive approaches are needed to support agricultural programmes to achieve SDG 2 targets on food and nutrition security (Hanjra et al. 2017c).

¹This work was presented at the European Commission Joint Research Centre workshop held in 2015 in Seville, Spain (see Acknowledgements).

4.1 *Rural Irrigation Schemes Using Surface and Groundwater*

4.1.1 **Public Investments: South Africa**

South Africa's national irrigation development plan prioritised the rehabilitation of old irrigation schemes and the development of new schemes to benefit smallholders. Research evidence has shown that irrigation has a very high social value for subsistence farmers and public investments offer remarkable returns in food security and social equality. The NIS database shows that South Africa has about 1.3 million ha under irrigation, but only 47,670 ha in 302 schemes are under smallholder irrigation (van Averbek et al. 2011). Located in former homelands, these schemes have the potential to contribute to food security and income and to create employment for the poor.

IWMI's Southern Africa regional office based in Pretoria, South Africa (IWMI SA) and national partners have accumulated vast knowledge over the past 20 years on agronomy, water management and revitalisation of irrigation schemes in Southern Africa. However, knowledge gaps remain in water economics, financial and investment analysis and policy measures to address the needs of smallholders and poor farmers. Smallholder irrigators lack experience, motivation, funds, assets, machinery and marketing skills to take full advantage of government funding targeting the rehabilitation of irrigation schemes to increase productivity, profitability and social integration of new entrants into the national fabric.

Data from irrigated areas in the **Limpopo basin** show that rural poverty varies widely between the basin states: in Zimbabwe (69%), Mozambique (68%), South Africa (56%) and Botswana (20%). Food insecurity had a lower range (0–40%) than poverty (0–95%). 'Areas of high food insecurity and poverty consistently coincide with areas experiencing low water availability' (Magombeyi et al. 2016: 20). Indeed, households with access to irrigation in the Limpopo province of South Africa are more food secure (86%) compared to dryland farmers (53%) (Oni et al. 2011). Irrigation increases crop yield, income, assets and farm diversification to enhance household food security. To further enhance food security, irrigators should be targeted for education and extension services, while food aid should be targeted to those households without access to irrigation and those with large families and few assets (e.g. agricultural land and tools). Policymakers need to support irrigation to assist farmers to produce their own food, to help break the food aid 'dependency syndrome'. Nutrition should be part of the public agriculture programme to promote a paradigm shift in local eating habits to combat undernutrition and obesity.

Despite public funding, amid poverty and lack of skills, smallholder farmers continue to prioritise low value crops for food security reasons. Data from the Mooi river irrigation scheme of **KwaZulu-Natal**, South Africa show that farmers applied less water (62%) to their potato crop (with a water value of USD 0.25 per m³) than to crops with a lower water value, such as maize (USD 0.12 per m³) and beans (USD 0.10 per m³) that are important for household food security (Muchara et al.

2016). As water is provided free to farmer groups, unequal distribution at tails and inefficient water use are common in this scheme. This suggests that cost recovery mechanisms and user participation policies can incentivise efficient water use. This observation is supported by evidence from the Tugela Ferry irrigation scheme in the Msinga District (Fanadzo 2012; Sinyolo et al. 2014; Maziya et al. 2017).

Data from 223 small farming households in the **Eastern Cape**, one of the poorest provinces in South Africa, show that maize yield will be positively affected by climate change under rainfed or irrigated conditions, while potato yield will decline. Both institutional and infrastructural support, through access to credit and irrigation facilities, were recommended for adequate adaptation to future climate change impacts on food security (Hosu et al. 2016). Public policies and planning processes should carefully consider such yield trade-offs in making integrated policies to enhance food security and sustainability at scale.

4.1.2 Public Private Partnerships Model: Zimbabwe

The NIS database for Zimbabwe shows that the total area equipped for irrigation is 186,000 ha, with 130,000 ha currently functional and 56,000 ha in need of rehabilitation. Zimbabwe has a total potential irrigable area of 2.5 million ha that could be developed at a total cost of about USD 10 billion, for which government needs to attract private sector investment into new irrigation developments (Table 1) (Hanjra et al. 2016b). This area spans old resettlement, communal, agriculture authority and new settlement farming sectors. It could be irrigated using water from existing and planned dams, and small, medium and large rivers and groundwater. However, the main challenges remain investment and sustainability.

Table 1 Current status and investment opportunities in irrigated farming systems in Zimbabwe

Sub-sector	Equipped	Functional	Under Rehabilitation
<i>Irrigated farming systems (ha, 2015)</i>			
Communal	15,000	10,000	5000
Old resettlement (A1)	30,000	23,000	7000
New settlement (A2)	61,000	22,000	39,000
Agriculture development authority (ARDA)	17,000	12,000	5000
Plantations	63,000	63,000	0
National total	186,000	130,000	56,000
<i>Investment opportunities</i>			
	Equipped	New irrigation	Under Rehabilitation
Capital cost (estimated) (USD million)	–	10,000	196
Financing model	Public	Hybrid	Public–private

Source Department of Irrigation (Hanjra et al. 2016b)

Detailed fieldwork in 14 smallholder irrigation schemes in the **Masvingo province of Zimbabwe** showed that common **drivers of success** of enhanced food security are proximity to markets, access to credit, contract farming, farmer organisation, crop choices, extension support, infrastructure maintenance and storage facilities (Hanjra et al. 2016b). Output marketing is a serious challenge in almost all rural schemes, and there is a need for grading and standardisation of weights and measures and quality assurance. Indeed, even town and city market traders rarely use scales, but instead use buckets, and other indigenous measures. Irrigation schemes directly selling to local institutions such as residential colleges, schools, hospitals, churches, and mining workers tend to be more productive and profitable. Irrigators follow cropping plans at scheme level and acquire inputs at competitive prices through group bargaining. Smallholder irrigators here are generally much better organised than smallholders across the border in South Africa. Most irrigation schemes have clear by-laws and rules but no recourse beyond their associations. For instance, after the rehabilitation of some surface irrigation schemes, food production improved dramatically and smallholders entered into joint production and marketing contracts with some supermarkets and fast food giants in South Africa. However, in order to take full advantage of these opportunities they needed government support and legal assistance in contract negotiation and enforcement.

Value addition activities such as tomato paste, dried packaged beans, maize cereals, roasted peanuts, and premium grade organic food production can add further value, but require storage, processing facilities and linkages with distant urban markets. Mobile phones allow smallholders to enquire about prices and do business with supermarkets and bulk buyers, but poor transport facilities make it expensive to sell small quantities in town and city markets (Hanjra et al. 2016b). Farmer training in business management and financial accounting offers high returns on investment. Energy shortages are a serious problem, particularly where pumping is required to pressurise mini sprinklers. Reverting to **gravity irrigation** or using **solar panels** are potential solutions.

4.1.3 Sustainable Intensification Business Model: Tanzania

The National Irrigation Master Plan 2002 identified the total potential irrigation development area at 29.4 million ha, including 2.3 million ha of high potential area. However, the actual area under irrigation is only 450,962 ha (Tanzania NIS database 2015) and there are 2427 small-scale irrigation schemes (Hanjra et al. 2016a). Tanzania's National Water Policy and Water Resources Management Act 2009 provides strong support for irrigation and sustainable intensification development. In many cases, smallholders initiate proposals for irrigation scheme development and complementary rural infrastructure including schools, roads and health centres, and manage the scheme under local by-laws with guidance from irrigation authorities. In-depth studies in seven smallholder irrigation schemes in the Ruvu River Basin and Morogoro region show successful transition from crop diversification to sustainable intensification. This covers the whole range of crop production, but the major

irrigated crop in Tanzania is rice. For example in the Ruvu Basin, rice yield has increased dramatically from 2 tonnes per hectare (t/ha) to about 5 t/ha (Fig. 2) and up to 8 t/ha with sustainable rice intensification (SRI). **Ruvu River branded rice is a successful business model.** Smallholders add further value through increased investment in output marketing, such as branded rice, smaller packaging and direct sale to town markets in partnerships with agribusiness. They also support infrastructure development such as local roads, storage, energy, water, schools and job training for irrigators to support transition to non-farm jobs in nearby towns and to attract private sector investment. Farmers are organised into Irrigator Associations and regular meetings ensure inclusivity and sustainability.

Irrigation schemes in the **Morogoro region** are a model for sustainable intensification. Here maize, paddy and beans are the predominant crops, but the sustainable intensification trajectory leads to the integration of vegetables first, followed by livestock and fruit orchards and finally fish in the most innovative schemes. For example, livestock integration into irrigated crop production in Kilosa district has enhanced food security and directly improved nutrition outcomes, due to greater milk and protein consumption at household level. Influx of large livestock herds during the dry season can cause serious damage to irrigation infrastructure. The **Kilosa district livestock grazing fee model is a business innovation** for enhancing profitability and sustainability. Some irrigation schemes have responded to the livestock challenge by offering fallow croplands to communal pastoralists/seasonal livestock herders to graze their animals on crop residues and after-harvest regrowth, in exchange for a levy per livestock unit (Hanjra et al. 2016a). The herder's livestock productivity improves (higher cow milk production and reduced calf mortality in the dry season) due to better quality and palatable feed. This business model brings new income for irrigators, which is partly used to maintain watercourses, while direct grazing or tethering brings free livestock manure to fallow fields to enhance soil fertility.

Many schemes practice irrigation using an irrigation business model, where smallholders pool their land and water resources to produce high value crops (chillies,

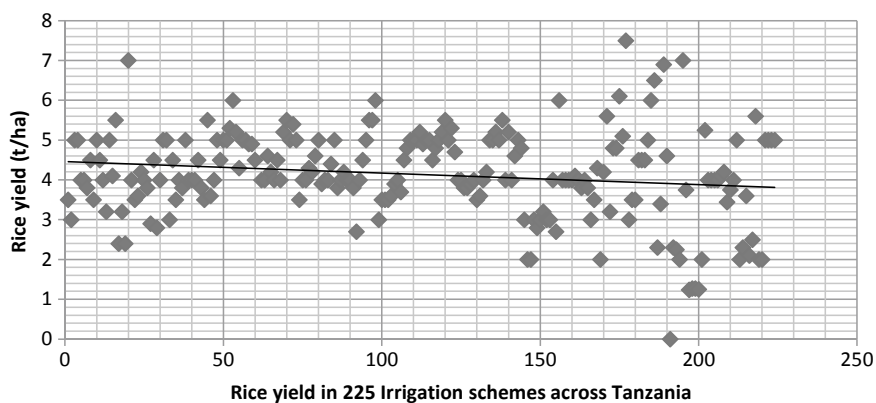


Fig. 2 Closing the yield gap, enhancing prosperity and sustainability (Hanjra et al. 2016a)

tomatoes and table grapes) for market sale through contracts with supermarket chains. Some schemes even undertake their own processing and marketing to sell branded rice (e.g. surface water irrigation, Ruvu basin), table grapes and bottled grape juice (e.g. groundwater irrigation, high-tech facility in Chamwino district). Indeed, the **Chamwino district grape production system is a business model innovation by smallholders**. Investment comes from commercial loans to install modern irrigation systems, such as pressurised drip irrigation using groundwater. Local political leadership, including district development authorities, provides strong support and loan guarantees to the agriculture development bank on behalf of smallholder farmers, who still work on their commercial farm as labourers, to hire service providers for technical works. Annual benefits are distributed equally among all the farmers (Hanjra et al. 2016a). Equal landholding and benefit sharing on business principles help to avoid equity problems. Member irrigators earn four times higher profit than non-irrigators, and many more farmers are registered to join the scheme on a first-come, first-served basis. This business model is gaining momentum and being scaled out to other irrigation districts.

4.1.4 West and East Africa

Past irrigation policy in many West African countries encouraged investment in large-scale irrigation for agricultural development and food security reasons, yet evidence of success remains inconclusive (Williams et al. 2012). Large-scale irrigation projects are expensive, per hectare and per person lifted out of poverty. Rice grown in some of these irrigation schemes could not compete until recently against cheaper imported rice in urban markets and was considered less attractive by large households and women shoppers (Demont et al. 2017). Due to low quality of local rice and high cost of production, rice production has low profitability, e.g. in **Niger** (Katic et al. 2013), **Benin** (Nonvide et al. 2017) and **Office du Niger**, Mali (USD 138 per ha) (Sidibé and Williams 2016). Farmers persist with irrigation as long as irrigation infrastructure works with minimum maintenance, as the real cost of rice production (4 tonnes paddy/ha) is high and sometimes exceeds return (Comas et al. 2012). Irrigators therefore tend to maintain a diverse portfolio of livelihood activities, including rainfed agriculture and non-farm activities. Households combine irrigated rice with traditional rainfed and flood-recession crops to enhance agricultural incomes. Rice yield has improved remarkably, for instance, by 60% in Benin (Nonvide et al. 2017). However, the high cost of using irrigation due to irrigation water not being available all the time, means that farmers tend to move in and out of irrigated farming depending upon the availability of loans and investment needs. Higher rice yield, water use efficiency, intensive use of irrigated land and greater emphasis on market-oriented production will translate into greater success. Investment in small-scale irrigation is supply-shifting, offering higher benefit to gender-equitable poverty reduction, but must be complemented by investment in demand-lifting interventions such as quality upgrading, branding and market promotion to achieve desired results.

Studies linking solar irrigation and food security linkages are limited in number (Burney et al. 2010; Alaofè et al. 2016). Data from Kalale district in northern **Benin** show that compared to manual irrigation, solar-powered drip irrigation greatly improves crop production diversity and dietary diversity (Alaofè et al. 2016). Women irrigators increase their production of vegetable (25%) and fruit (55%) and consumption threefold, thereby improving household food and nutrition security. In addition, the purchase and consumption of other food items, including sorghum, oil, rice and fish also increased. Many women used their additional income on food (60%), health (55%), utilities (40%) and education (25%). Thus, solar irrigation offers potential to enhance household nutritional status through direct food consumption and to increase income to improve access to health and education.

Similar impacts on food security and poverty reduction have been widely reported for smallholder irrigation in **Ethiopia** using surface water (Hanjra et al. 2009a), groundwater (Hagos and Mamo 2014), both surface and groundwater (Zeweld et al. 2015), spate irrigation (Hagos et al. 2017) and in other countries (Fig. 3).

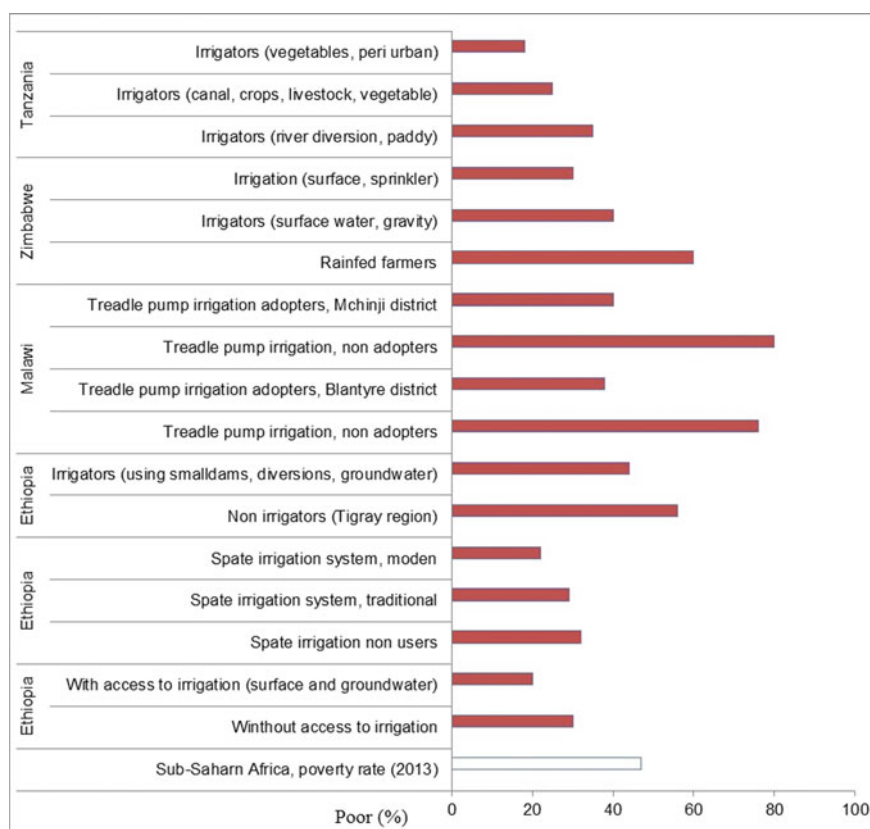


Fig. 3 Water management solutions and poverty reduction across SSA

Pathways linking irrigation with nutrition and health gains remain understudied. Only a few rigorous studies assess the linkages between irrigation and nutrition, but most show a positive effect of irrigation interventions on food security (Domènech 2015). In a review of (28) studies mainly focusing on SSA, only one study had assessment of nutrition outcomes as a primary objective. The study by Hagos et al. (2017), however, did not find any evidence of nutrition outcomes attributable to spate irrigation in Ethiopia. Other studies report mixed or inconclusive results. A study in Ghana (Namara et al. 2011) found inconclusive evidence on household dietary diversity score for rainfed versus groundwater irrigation. Data from **Burkina Faso** on household and child nutrition and dietary diversity measures showed an increase in household micronutrient-rich foods, such as dark green leafy vegetables and yellow or orange fruits, and maternal and child intake of leafy vegetables or eggs as a result of irrigation (Olney et al. 2015). A study in **northern Mali** (Dillon 2011) showed that between 1998 and 2006, households with access to irrigation greatly increased their daily calorie intake (1836 cal) compared to those without irrigation (925 cal), suggesting that irrigation helped to improve calorie intake over time. Also, a study in Zimbabwe that examined the linkages between irrigation and dietary diversity ranked independent irrigators (highest), and scheme irrigators, home gardens and non-irrigators (lowest), based on diversity of food produced and weekly food consumption (Moyo and Machethe 2016).

4.2 Urban and Peri-urban Agriculture Using Wastewater and Groundwater

Urban and peri-urban agriculture can contribute towards food and nutrition security and poverty reduction through more nutrient-rich food and direct market access than traditional irrigated agriculture producing cereals. The focus on fruits and vegetables supports, in particular, improved **nutritional benefits**. Various studies demonstrate the linkage between agricultural interventions and nutrition outcomes, showing that the production of targeted nutrient-rich crops, home gardens, and diversification of agricultural production systems towards fruits, vegetables and aquaculture can potentially improve nutrient intake and nutrition outcomes (Zezza and Tasciotti 2010; Pandey et al. 2016).

Peri-urban areas continue to expand fast amid urbanisation in Africa, creating the challenge of turning increasing quantities of wastewater and urban organic waste into opportunities for reuse and recycling in agriculture. With rising demand for fresh vegetables in cities, local production within and around urban areas across Africa is increasingly specialising in highly profitable irrigated vegetable production. For instance, **Accra, Ghana**, has some 800–1000 vegetable farmers cultivating unused open spaces near streams and drains within its core area, producing exotic vegetables (lettuce, cabbage, spring onions and cauliflower) and local vegetables (tomatoes, okra and chilli peppers). Sources of water are shallow wells and streams carrying

wastewater. Watering cans are used for fetching wastewater from drains, which is very labour intensive as the hot climate especially in West Africa demands daily or twice-daily irrigation. Therefore, plots cultivated per farmer are usually small (0.01–0.05 ha). Motorised pumps allow larger plots and they are increasingly used and shared among farmers where the distance between water source and fields is long. But even then, farmers still use watering cans to draw water from on-farm storage reservoirs filled by pumping (Drechsel and Keraita 2014: 3).

High market demand, close market proximity and year-round availability of (waste) water are the main drivers of urban and peri-urban vegetable production (Drechsel and Keraita 2014). Vegetable farming is a profitable venture, such that two out of every three vegetable farmers were unwilling to leave even if they were offered regular salaried jobs. Potential health risks exist but have not stopped farmers from gaining a livelihood by using ‘unsafe’ water for irrigation as this leads to higher profits compared with rural rainfed farming on similar sized-plots. Other studies provide supportive evidence on the acceptance of wastewater use in urban and peri-urban areas in Morogoro, **Tanzania** (Samson et al. 2017), Bulawayo city in **Zimbabwe** (Makoni et al. 2016), Blantyre, Lilongwe and Mzuzu in **Malawi** (Msilimba and Wanda 2012; Holm et al. 2014), and Addis Ababa, **Ethiopia** (Wedesilassie et al. 2011). The main risk is less with the farmer, but with the large number of consumers who maybe unaware of the water source used. IWMI estimates that in Ghana, the ‘beneficiaries’ of urban vegetable production include about 2,000 urban farmers, 5,300 street food sellers and 800,000 daily consumers within the major cities (Drechsel and Keraita 2014: 3). Benefits from urban farming manifest in different ways as shown by reports across Africa summarized below.

In **Accra, Ghana**, the wastewater of about 225,000 residents—some 14% of the total urban population—currently has a ‘natural’ wastewater treatment system that is not disposal-oriented, but turns wastewater into an asset through its use in irrigated open-space farming. This number is probably larger than the one served by sewerage and existing treatment plants in the city (Lydecker and Drechsel 2010). Urban market gardening is generally practised on large open areas not used for other commercial purposes, or in home gardens (backyards). Overall, open-space farming mainly supports cash-crop niche markets (e.g. for exotic vegetables), while backyard farming supplies household food subsistence needs and thus serve to reduce household food expenditure.

In **Zambia**, a quarter of urban households engage in urban agriculture, growing vegetables and other crops. Low-income city gardeners make USD 230 per year from sales (FAO 2012). Home gardening accounts for nearly half of fruit and vegetable production. In Lusaka, 90% of the residents practising urban agriculture in 2005 were women and for the majority it provided nearly one quarter to one half of their income, with 70% of growers cultivating small fields of less than 0.5 ha. A survey in four Zambian cities—Lusaka, Kabwe, Kitwe and Ndola—found that maize was the most frequently grown crop, but half of production consisted of horticultural crops: pumpkins, beans, onions, rape, tomatoes, groundnuts, sweet potatoes and cabbage (FAO 2012). Also, 80% of Lusaka’s supply of leafy rape is produced locally and marketed through small vendors in city streets and neighbourhoods, while revenue

from sales accounts for 18% of annual household income in Lusaka and about 50% in the other three cities (FAO 2012).

In Zimbabwe, around 70% of urban households practise some form of urban agriculture on residential land in the capital city of Harare, with about 17% practising it outside the residential properties in the vicinity of water bodies (Hanjra et al. 2017a). The streams and wetlands around the city often receive wastewater and this co-mingled water supports agricultural activities and contributes to food security and nutrition for the urban poor. Data around Bulawayo city for 2006 showed that some 500 farmers were using wastewater for irrigation of vegetable crops on small plots of half a hectare each (Mutengu et al. 2007). This is also supported by recent work (Makoni et al. 2016).

In Malawi, urban agriculture has social value for food security of poor households. About 25% of the population live in urban areas and use wastewater for irrigated agriculture (Msilimba and Wanda 2012). The 2030 Urban Structure Plan of Lilongwe City (GoM 2013) notes that ‘urban agriculture mainly consists of illegal farming practised seasonally in open spaces in the city’ and ‘it should be regulated land use’ for ‘commercial farms in the future’ (p. 26).

In East African capitals including **Addis Ababa**, **Dar-es-Salaam**, **Kampala** and **Nairobi**, the proportion of urban households that are farming (25–55%) has not diminished with urban growth, and urban farming households are better off (Lee-Smith 2010). Socio-economic benefits of wastewater irrigation are widely documented (Hanjra et al. 2015a; Makoni et al. 2016). For example, in **Moshi Municipality, Tanzania**, the use of treated wastewater in urban agriculture improved incomes and provides employment. However, improperly practised effluent irrigation is associated with public health risks to workers. Despite this, it still has positive social and economic implications and wastewater irrigation practitioners continue to do it (Kihila et al. 2014). Data from Dar-es-Salaam for the period from 1992 to 2005 (Drechsel and Dongus 2009) showed that total production areas are relatively stable. In recent times, crop production in urban open spaces by residential suburban cultivators in Dar-es-Salaam appears to be a market-driven, highly productive and profitable business activity (Owens 2016). However, the common use of polluted water limits official support for irrigated urban farming. Farmers in **Yaoundé, Cameroon** using wastewater irrigation can sell vegetables in the dry season at double the price of wet season production, and incomes were nearly 50% above the minimum wage, with leafy vegetables providing 8% of protein and 40% of calcium intake of all urban consumers. In Dar-es-Salaam, 67% of farmers had higher than average incomes, with 90% of leafy vegetables and 60% of milk consumed coming from urban and peri-urban agriculture. All crop farmers in Addis Ababa had incomes well above the median national income.

Integrating urban agriculture into urban planning can enhance the benefits of wastewater irrigation in urban and peri-urban areas. Examples include ‘green zones’ for horticulture in Maputo city, while the city of Ndola in Zambia has recognised crop and livestock production as legitimate land uses in its strategic plan. Many other cities have responded with policy initiatives (Table 2).

Table 2 Policy initiatives supporting urban agriculture in selected African cities

City, country	Policy
Maputo, Mozambique	Long recognised urban agriculture and supported 'green zones' for horticulture
Ndola, Zambia	Recognised crop and livestock production as legitimate land uses in its strategic plan
Lilongwe, Malawi	The 2030 Urban Plan recognises urban agriculture as regulated land use, although raw wastewater use is still against the policy framework in Malawi
Gaborone, Botswana	Established a national incubator providing training to farmers across the country on wastewater irrigation for vegetable production and business skills development
Dar-es-Salaam, Tanzania	Urban agriculture built into Agriculture and Livestock Policy and official planning and management; city provides improved extension services to help build farmers' organisational capacity
Kampala, Uganda	City Council has a Department of Agriculture and provides extension services to farmers, by-laws governing urban agriculture, a typology, and longitudinal measurement of its scale and extent (best practice)
Nairobi, Kenya	Urban agriculture incorporated into national land policy, adopted by parliament in 2010; municipal councils developed by-laws; farmers formed a gender-balanced network
Accra, Ghana	Due to the decentralisation of agricultural ministry, there is also a Directorate for Farming in Accra, providing extension services and support to urban farmers on learning how to organise, advocate, and increase their efforts towards land security, but also tackle issues in accessing safe water for irrigation

Source Authors

4.3 Big Data

Structural transformation and nutrition: Analysis of multi-year data for 29 developing countries shows that structural transformation increases total income, and that poverty falls faster with stronger support for agriculture (Webb and Block 2012). In turn, poverty reduction supports improved nutrition, especially in rural areas. The transformation process must be managed through targeted support for smallholder agriculture.

Drivers of food security: Big Data for small farms, including 13,000 farm households from 93 sites in 17 countries across contrasting agro-ecologies, show that the main drivers of food availability in SSA are crop production, off-farm income and market access. Crop production is the major source (63%) of food availability. Off-farm income contribution ranged from 12% for households without enough food

available to 27% for households with sufficient food available. Only three key variables (household size, number of livestock and land area) can predict food availability for 72% of households (Frelat et al. 2016), but market access strongly influenced these linkages. This calls for multisector policy harmonisation, incentives and income diversification, instead of a singular focus on area expansion for agricultural development.

Yield gaps are poverty gaps: Household panel data from 21 regions in eight SSA countries show that poverty gaps are increasing with yield gaps, particularly in low potential areas (Dzanku et al. 2015). Indeed, yield gaps are increasing with expansion of cultivated area into marginal lands. Instead of area expansion, investments in intensification and irrigation development could help to close both yield and poverty gaps.

Urban and peri-urban agriculture: IWMI and the University of California, Berkeley modelled the use of polluted water in farming on a global scale. Study results show that 65% of all irrigated areas less than 40 km downstream of urban centres—about 35.9 million ha worldwide—are affected by wastewater flows (Thebo et al. 2017). Of this total area, 29.3 million ha is in countries with very limited wastewater treatment; thus, wastewater reuse provides economic opportunities for smallholders, but exposes 885 million urban consumers, farmers and food vendors to health risks. This calls for urgent investments to enhance the recovery of water, nutrients and energy from wastewater for safe reuse, thus transforming urban wastewater into an economic asset (Hanjra et al. 2015b; Miller et al. 2017). These investments will also improve public health, consumer safety and food handling.

4.4 Telecoupling and Irrigation Development

Water development and irrigation investments increase the interconnectedness of hydrologic and socioeconomic systems and can have cascading effects known as ‘telecoupling’, i.e. socioeconomic and environmental interactions in coupled human and natural systems at different scales over great distances (Liu et al. 2013). Telecoupling in water development can significantly influence the outcomes and sustainability of development projects. For example, Ethiopia receives about half of its annual budget from foreign development assistance. Water development is linking its hydrology with distant communities and markets, creating new flows of people, materials and investments. This is resulting in cascading impacts and feedback between urbanisation, the economy and the water-food-energy nexus in East Africa (Chignell and Laituri 2016).

Policy changes in leading global economies (USA, China, Brazil and India) will have collateral effects in vulnerable countries in Africa. For example, China in a bid to improve trade to bridge the gap between food production and consumption is supporting **large water transfer projects** in some African countries (for example, Botswana, Namibia, Lesotho and South Africa), and the world’s largest and

longest one, the South-North Water Transfer Scheme in China with a planned investment of USD 77 billion (Liu et al. 2013). Other examples include the growing demand for **biofuels** and large-scale agricultural land acquisitions which may take water away from human food systems, (Williams et al. 2012; Schoneveld 2014), **conservation investments** such as payments for ecosystem services and rising global **food trade**.

Asian irrigation and the development of West African irrigation is strengthening interconnections between humans and nature (Im et al. 2014; de Vrese et al. 2016). Irrigation development changes agrifood systems over large distances, with spillover effects on food security and land use dynamics. Smallholder farmers in Africa are not just **beneficiaries** of irrigation development through satisfaction of their own food security. They are also **agents** of change, playing a significant role in cumulative irrigation development and influencing complex drivers that transcend spatial, institutional and temporal scales (Table 3).

Table 3 What smallholders contribute to irrigation development and transformational change

Contribution	Remarks
Investments	African farmers invest significantly in irrigation development (capital, labour, canals, pumps, machines, infrastructure, management) beyond official statistics
Innovations	Production practices, site selection, technology adoption/copy, new investment patterns, rural–urban market linkages
Social networks	Farmer interactions with outside agents (informal trading networks, agrodealers, pump mechanics, mobile phone and Internet, contractors, extension, engineers, authorities, civil society, donors) promoting change
Markets	City and regional markets, cash, credit, output and input linkages, transport, banking, finance
Resource management	Sustainable management of land, water, energy and food, despite land tenure risk
Infrastructure	Maintenance of irrigation schemes, canals, roads, bridges, schools, health centres
Knowledge	Indigenous knowledge, ancient water management practices, landraces, customs, traditions, risk management strategies
Youth engagement	Youth engagement in agriculture; youth retention in traditional artisan communities; youth training to provide future generation of irrigators
Human migration	Reduced rural–urban out-migration due to irrigation development; employment of young migrants (e.g. from Burkina Faso in Accra’s urban agriculture using wastewater irrigation; farmworkers returning from Zimbabwe to central Mozambique’s mountainous irrigation area); labour mobility to large-scale irrigation development schemes and population settlement in uninhabited areas
Food trade	Increased market sale; supply contracts with supermarkets; informal regional market links; pan-African food trade

Source Authors

5 Discussion: Transforming Investments to Feed the Future

There is no reason why Africa cannot be self-sufficient when it comes to food. It has sufficient arable land. What's lacking is the right seeds, the right irrigation, but also the kinds of institutional mechanisms that ensure that a farmer is going to be able to grow crops, get them to market, get a fair price.

US President Barack Obama, G8, Italy, 10 July 2009. (Cited in Lankford 2009: 476)

5.1 *Investing in Small-Scale Irrigation and Complementary Infrastructure*

A review of 104 studies (82% of them from Africa) indicates that enhancing future food security will require a primary focus on sustainable intensification of African smallholder farming systems along five domains: productivity, economics, environment, social and human well-being (nutrition and social equity). **Strong metrics exist for all domains except social and human well-being which have major gaps** (Smith et al. 2017). Gains in smallholder productivity and poverty reduction are far greater when irrigation investments are combined with complementary interventions in infrastructure—energy, rural roads and rural vehicle supply to ease movement of input and output from farms (Tamene and Megento 2017)—and in services—education and market access—for smallholder irrigators (Hanjra et al. 2009a).

Africa faces unique policy and investment challenges, as smallholders are among the poorest and most food insecure amid droughts and water poverty (Hanjra and Gichuki 2008). For example, about 90% of Africa's arable land is concentrated in just nine countries (Jayne et al. 2014); vast areas are uninhabited and utilisation of available arable land is limited due to lack of investment (Chamberlin et al. 2014); and population is clustered in some areas with unsustainable intensification (Jayne et al. 2014). Livelihood opportunities outside the farming sector must improve to create faster growth in rural non-farm employment (Ricker-Gilbert et al. 2014), along with better population planning and policies (Headey and Jayne 2014).

Africa faces the largest food gap, with its cereal demand tripling by 2050. This will require sustainable intensification, including significant increase in yield, cropping intensity and sustainable expansion of irrigated production (van Ittersum et al. 2016), and water-smart agricultural practices (Nicol et al. 2015). Data spanning 43 years show that climate-smart agriculture in Nigeria will require more area under irrigation to enhance the development of all sub-sectors of agriculture for future food security (Olayide et al. 2016).

5.2 Groundwater Development Policy

A boom in African groundwater utilization is a pre-requisite for irrigation development and improved well-being (Villholth 2013). Africa is nowhere near the level of groundwater use in agriculture in Asia. For example, groundwater accounts for nearly 50% of irrigated area in India (Giordano 2009) whereas it is a relatively underutilised resource in SSA, providing less than 7% of irrigation water. Investments need to be directed particularly towards (i) estimating availability of shallow groundwater to identify high-yielding local sites suited to smallholder irrigation development (Ebrahim and Villholth 2016); and (ii) providing access to affordable energy sources, to drill boreholes and pump water for irrigation (Villholth et al. 2013). Transition to groundwater seems feasible for the **sustainable intensification** of irrigated agriculture, notwithstanding the complex bottlenecks such as incomplete knowledge of groundwater availability, high energy costs, poor market and infrastructure and acute seasonal labour shortages (Amjath-Babu et al. 2016). The strategic importance of groundwater for global water and food security will likely intensify under climate change adaptation strategies (Taylor et al. 2013). Groundwater acts as a buffer against impacts of climate variability and alleviates poverty in low-income settings by reducing crop failure and increasing yields and incomes (Richs and Vrba 2016) and hydroclimatic extremes such as droughts and floods (Pavelic et al. 2015). In Oman, modern groundwater irrigation methods, such as drip irrigation for vegetable production, enhance crop water productivity and economic returns (Al-Said et al. 2012). However, costs and investments needed for groundwater development and pumping are prohibitively high; requiring public financing and cost-sharing business models targeting smallholders (Gebregziabher et al. 2013). For instance, in the Saiss plain in **Morocco**, the boom in groundwater economy benefited entrepreneurial and more affluent farmers, but their greater access to capital and state subsidies contributed to the marginalisation of smallholders, increasing socio-economic inequalities despite rapid transformation (Ameur et al. 2017).

Groundwater policy interventions must target different issues at different scales—local, national and river basin—and involve both formal and informal actors. A systematic review of 37 studies of pumped irrigation systems in 13 countries found: eight countries where motorised pumps are used (**Mauritania, Ethiopia, Nigeria, Mali, Niger, Kenya, South Africa, Malawi**), four where treadle pumps are used (**Malawi, Zimbabwe, Ghana, Kenya**), two where solar pumps are used (**Benin, Ethiopia**) and one where rope pump is used (**Zimbabwe**), but none using wind pumps (Kamwamba-Mtethiwa et al. 2016). The choice of pump and energy is important and must take advantage of recent advances in science and technology. Also, groundwater development policy must be inclusive. Three case studies in **Morocco, Tunisia** and **Algeria** showed that, although groundwater supply chain actors are often informal and operate at the margin of public policy, they are catalysers for groundwater development and their greater involvement can reduce risks, facilitate access to credit and subsidies and dissemination of innovations in groundwater development (Lejars et al. 2017).

5.3 *Investing in Solar Energy for Groundwater Pumping for Irrigation*

Investment in solar energy is needed to promote small-scale distributed irrigation across SSA, where feasible. Mobisol, a German solar company working in Tanzania in partnership with **USAID's Power Africa initiative**, provides solar panels to enable customers use power welding and pipe-cutting equipment, water pumps, egg incubators and fans to make cooking stoves more fuel-efficient. **Scaling Solar**, an initiative of the World Bank, supported an auction in Zambia to introduce and procure solar energy quickly and at very competitive prices—6.02 US cents per kWh, compared to oil-based power which can be three to four times as expensive (Brookings 2016). **Madagascar** and **Senegal** are also participating in a Scaling Solar initiative that could amount to nearly USD 1 billion of investment. **New Deal on Energy in Africa**, a multi-billion-dollar initiative by AfDB, aims to establish 75 million new off-grid connections. Since the launch of USAID's Power Africa in 2013, the programme's off-grid partners have added about 2.5 million new connections (Brookings 2016).

Investment in solar energy in Africa will support agricultural transformation and enhance food security. Solar irrigation has positive effects on labour saving, crop yield and profits on smallholder farms in Ethiopia. Investment in solar technology and upstream pumping for large-scale land reclamation projects in the **Sinai desert, Egypt** and solar energy farms in the Israel desert (Fischhendler et al. 2016) provide useful examples that could revolutionise agriculture in **MENA** and dry regions of SSA. The declining cost of solar panels could expand groundwater use in agriculture. Yet, for uptake by smallholders, the capital cost of solar irrigation pumps (USD 650–3000) must become competitive in comparison to fuel/electric pumps (USD 300–1500) or treadle pumps (USD 25–100). India, for example, has over 11.5 million electric and 6.7 million diesel pumps, but only 2000 solar irrigation pumps (Shah et al. 2014).

New solar pump policy for irrigation should enhance solar power for food security. This requires a supportive business model that packages **conditional subsidies**—linked to compliance with design regulations, crop water requirements and regular monitoring and reporting and **targeted subsidies** for smallholders that allow only smaller solar irrigation pumps (1.5–2.5 kWp) for groundwater irrigation. Solar water pumps could be widely adopted with policy support (subsidy, tax exemption, access to technologies, finance and markets) to address initial affordability problems and facilitate solar power concentration storage in batteries. A solar irrigation policy package, comprising capital cost subsidy and guaranteed buyback of surplus power, could transform both the energy and groundwater economies. The energy payback period would be shorter and surplus solar energy buyback income would encourage farmers to raise the productivity of both groundwater and solar energy, by investing in micro-irrigation and choosing crops with high returns on irrigation. Solar irrigation is aligned with government policy priorities in Ethiopia, Jordan, Morocco, Egypt and Zambia. In off-grid areas, supportive policies are needed to co-optimize solar

panels, batteries and water pumps. Solar irrigation saves on fuel costs, by replacing petrol and diesel while also earning revenue from charging mobile phones—at ETB 2 (7 US cents) per phone—and selling water to neighbouring farmers. Decentralised solar power generation in remote villages and rural irrigation schemes could enhance local food security.

5.4 Investment in Peri-urban and Urban Agriculture

To support peri-urban and urban agriculture and promote safe reuse of wastewater, policy must address the current mismatch between national food security policies and urban bias, e.g. maize policy in Zambia (Hanjra and Culas 2011). While investment in rural irrigation schemes will remain key to food security, greater attention must be paid to specific challenges in sustainably feeding urban areas. This should involve harmonisation of national food security policy with urban planning that widens the mandate of city councils beyond waste disposal to supporting safe reuse in urban and peri-urban agriculture, in close coordination with irrigation authorities, energy authorities, groundwater management boards, farmers and urban planners (Connor et al. 2017; Hanjra et al. 2017b). To that end, the following key policy implementation strategies are suggested (Hanjra et al. 2017b, d).

- Integrate urban and peri-urban agriculture into national policy processes.
- Provide social incentives and public subsidies on a par with the fertiliser and bioenergy economy, to upscale wastewater irrigation and nutrient reuse in agriculture.
- Mandate estate developers to allocate land parcels for community gardens and residential complexes to undertake onsite wastewater treatment for reuse in order to boost local food production and promote social cohesion.

5.5 No-Regret Investments for Managing Social Change

The nature of social change and associated vulnerabilities due to climate change are not well understood (Nelson et al. 2016). Scenario exercises for 2030 conducted by IWMI in East Africa, involving national policy experts and regional stakeholders, show how the relative usefulness of capacity development approaches compared to impact approaches to adaptation planning differs with the level of uncertainty and associated lead time (Vermeulen et al. 2013). **Capacity development approaches** are important for incremental adaptation and innovation, through institutional support to farmers (e.g. financial services education and participatory rehabilitation of existing irrigation schemes) that are feasible, cost-effective and low-risk response.

Impact approaches, involving wholesale reconfiguration of food and farming systems, large-scale anticipatory investments in irrigation and other infrastructure, livelihood diversification and population migration to better endowed areas, are particularly important for transformative adaptation. To avoid disruptive social change, such innovations require strategic guidance on agricultural water management and water policy in order to make long-term **no-regret interventions**. These could include investments in wastewater reuse for irrigation; wider storage options beyond surface reservoirs, including groundwater as a buffer against long-term droughts (Scanlon and Vladimir 2016); micro-irrigation technologies; rainwater harvesting; farmer gene banks (e.g. ICARDA's global seed vault in a remote island of Norway); indigenous crop races; and cultivation of wild foods and hardy land races under rainfed systems. This would help to prepare against catastrophic risks and safeguard food security and sustainability into the distant future.

6 Conclusions and Outlook

This chapter presented evidence on irrigation and food security linkages across Africa and produced three major conclusions. Firstly, investments in irrigation contribute to poverty reduction. Here, 'irrigation' refers to surface water and groundwater use in rural irrigation schemes, as well as wastewater use for food production in rural, peri-urban and urban areas. Secondly, strong evidence exists that investments in irrigation enhance food security. Thirdly, existing evidence is supportive but still insufficient to draw broader conclusions on nutrition outcomes, primarily because nutrition is only now being considered as an explicit objective of irrigation development and agriculture policy (Pingali 2015). Nutrition-sensitive irrigation programmes and delivery platforms are therefore needed to help realise the full potential of irrigation for enhancing both food and nutrition security (Hanjra et al. 2017c). Strategic priorities to enhance food and nutrition security are investments in smallholder rural irrigation schemes, peri-urban and urban agriculture, and related support measures, including rural infrastructure and solar energy for well-distributed irrigation development.

There is a need to frame 'irrigation' to integrate socio-economic and environmental interactions affecting sustainability, across local to global levels, through tele-coupling. **System integration and sustainability** can transform how policymakers think about irrigation and agricultural water management and facilitate the training of a new generation that is well-equipped to develop food security and environmental sustainability solutions. There is also a need to realise the productive function of urban and peri-urban agriculture within urban planning, and a need for better integration of food and nutrition security issues in land use planning, especially within wastewater sanitation systems in cities and towns across Africa.

Acknowledgements This work was supported by the CGIAR Research Programme on Water, Land and Ecosystems (WLE), led by IWMI. The work was presented at the European Commission

Joint Research Centre (JRC) workshop, held in November 2015 in Seville, Spain. We gratefully acknowledge the constructive feedback and guidance of workshop participants which helped to improve the work, and the financial support from JRC Seville, Spain, to the first author to attend the workshop.

Appendix: Indicators of Regional Change and Transformation in SSA

World Bank data showed that, over the period 1990–2013, population growth remained high (2.7% per annum). Agricultural productivity growth is continuing but not apace to feed the population. Majority of the poor (82%) still live in rural areas and the majority of rural households (69%) earn income from agriculture. The share of agriculture in employment (61%) and GDP (25%) is still high resulting in widespread poverty (417 million people) across major agro-ecological zones in Africa. Real agricultural value added has been growing (4.1%) over the period 1990–2013, but this was countered by high population growth and grew only slowly (1.4%) in per capita terms (Barrett et al. 2017). Food security has improved, largely due to annual growth in cultivated area under cereals (1.3%), but cereal yield growth (1.6%) has been far lower than in Asia during the Green Revolution. Africa yield levels started from a very low base and remain low. For example, average cereal yield in Africa today (about 1.5 t/ha) is less than half of the level in South Asia (3.1 t/ha), about a quarter of the level in China (6 t/ha) (Barrett et al. 2017), and about one eighth of the level in Australia.

Structural transformation in Africa has been towards low productivity, non-tradable services in urban areas, rather than tradable manufacturing (Rodrik 2016). This has ignited urbanisation and the emergence of consumption cities (Gollin et al. 2016), with large metabolic throughput of water, food and energy and a rising share of food imports to ensure local food security. Such resource-driven urbanisation and structural transformation has led to expansion in slums, poor water and sanitation services, a widening rural-urban income gap and inequality (Gollin et al. 2016).

References

- Abro, Z. A., Alemu, B. A., & Hanjra, M. A. (2014). Policies for agricultural productivity growth and poverty reduction in rural Ethiopia. *World Development*, 59, 461–474.
- AfDB. (2016). *Feed Africa—Strategy for agricultural transformation in Africa: 2016–2025*. African Development Bank.
- Alaofè, H., Burney, J., Naylor, R., & Taren, D. (2016). Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in Northern Benin. *Food and Nutrition Bulletin*, 37, 164–175.
- Al-Said, F. A., Ashfaq, M., Al-Barhi, M., Hanjra, M. A., & Khan, I. A. (2012). Water productivity of vegetables under modern irrigation methods in Oman. *Irrigation and Drainage*, 61, 477–489.

- Ameur, F., Kuper, M., Lejars, C., & Dugué, P. (2017). Prosper, survive or exit: Contrasted fortunes of farmers in the groundwater economy in the Saiss plain (Morocco). *Agricultural Water Management*, 191, 207–217.
- Amjath-Babu, T. S., Krupnik, T. J., Kaechele, H., Aravindakshan, S., & Sietz, D. (2016). Transitioning to groundwater irrigated intensified agriculture in Sub-Saharan Africa: An indicator based assessment. *Agricultural Water Management*, 168, 125–135.
- Barrett, C. B., Christiaensen, L., Sheahan, M. B., & Shimeles, A. (2017). *On the structural transformation of rural Africa* (Policy Research Working Paper 7938). Washington, DC: The World Bank.
- Bren d'Amour, C., Reitsma, F., Baiocchi, G., Barthel, S., Güneralp, B., Erb, K.-H., et al. (2016). Future urban land expansion and implications for global croplands. *Proceedings of the National Academy of Sciences*.
- Brookings. (2016). *The US-Africa business forum: Investing in solar energy*. Retrieved January 15, 2016, from <https://www.brookings.edu/blog/africa-in-focus/2016/09/15/the-us-africa-business-forum-investing-in-solar-energy/>.
- Burney, J. A., & Naylor, R. L. (2012). Smallholder irrigation as a poverty alleviation tool in Sub-Saharan Africa. *World Development*, 40, 110–123.
- Burney, J., Woltering, L., Burke, M., Naylor, R., & Pasternak, D. (2010). Solar-powered drip irrigation enhances food security in the Sudano-Sahel. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 1848–1853.
- Carletto, G., Ruel, M., Winters, P., & Zezza, A. (2015). Farm-level pathways to improved nutritional status: Introduction to the special issue. *The Journal of Development Studies (Special Issue)*, 51, 945–957.
- Chamberlin, J., Jayne, T. S., & Headey, D. (2014). Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy*, 48, 51–65.
- Chignell, S. M., & Laituri, M. J. (2016). Telecoupling, urbanization, and the unintended consequences of water development aid in Ethiopia. *Geological Society of America Special Papers*, 520, 125–135.
- Comas, J., Connor, D., Isselmou, M. E. M., Mateos, L., & Gómez-Macpherson, H. (2012). Why has small-scale irrigation not responded to expectations with traditional subsistence farmers along the Senegal River in Mauritania? *Agricultural Systems*, 110, 152–161.
- Conceição, P., Levine, S., Lipton, M., & Warren-Rodríguez, A. (2016). Toward a food secure future: Ensuring food security for sustainable human development in Sub-Saharan Africa. *Food Policy*, 60, 1–9.
- Connor, R., Renata, A., Ortigara, C., Koncagül, E., Uhlenbrook, S., Lamizana-Diallo, B., et al. (2017) *The United Nations world water development report 2017. Wastewater: The untapped resource*. New York, NY.
- de Vrese, P., Hagemann, S., & Claussen, M. (2016). Asian irrigation, African rain: Remote impacts of irrigation. *Geophysical Research Letters*. <https://doi.org/10.1002/2016gl068146>.
- Demont, M., Fiamohe, R., & Kinkpé, A. T. (2017). Comparative advantage in demand and the development of rice value chains in West Africa. *World Development*. <https://doi.org/10.1016/j.worlddev.2017.04.004>.
- Dillon, A. (2011). The effect of irrigation on poverty reduction, asset accumulation, and informal insurance: Evidence from Northern Mali. *World Development*, 39, 2165–2175.
- Dixon, J., Garrity, D., Boffa, J.-M., Williams, T., Amede, T., Auricht, C., et al. (Eds.). (2017). *Farming systems and food security in Africa: Priorities for science and policy under global change*. London and New York, NY: Routledge.
- Domènech, L. (2015). Improving irrigation access to combat food insecurity and undernutrition: A review. *Global Food Security*, 6, 24–33.
- Drechsel, P., & Dongus, S. (2009). Dynamics and sustainability of urban agriculture: Examples from Sub-Saharan Africa. *Sustainability Science*, 5, 69.

- Drechsel, P., & Keraita, B. (Eds.). (2014). *Irrigated urban vegetable production in Ghana: Characteristics, benefits and risk mitigation* (2nd ed., 247 pp). Colombo, Sri Lanka: International Water Management Institute (IWMI).
- Dzanku, F. M., Jirström, M., & Marstorp, H. (2015). Yield gap-based poverty gaps in rural Sub-Saharan Africa. *World Development*, 67, 336–362.
- Ebrahim, G. Y., & Villholth, K. G. (2016). Estimating shallow groundwater availability in small catchments using streamflow recession and instream flow requirements of rivers in South Africa. *Journal of Hydrology*, 541, 754–765.
- Fan, S., Hazell, P., & Haque, T. (2000). Targeting public investments by agro-ecological zone to achieve growth and poverty alleviation goals in rural India. *Food Policy*, 25, 411–428.
- Fan, S., Gulati, A., & Thorat, S. (2008). Investment, subsidies, and pro-poor growth in rural India. *Agricultural Economics*, 39, 163–170.
- Fanadzo, M. (2012). Revitalisation of smallholder irrigation schemes for poverty alleviation and household food security in South Africa: A review. *African Journal of Agricultural Research*, 7, 1956–1969.
- FAO. (2012). *Growing greener cities in Africa. First status report on urban and peri-urban horticulture in Africa*. Rome: Food and Agriculture Organization of the United Nations.
- FAO. (2015). *Regional overview of food insecurity: African food security prospects brighter than ever*. Accra, Ghana: Food and Agriculture Organization of the United Nations.
- FAO. (2019). *The state of food security and nutrition in the world. Safeguarding against economic slowdowns and downturns*. Rome: Food and Agriculture Organization of the United Nations, Rome.
- Fiorella, K. J., Chen, R. L., Milner, E. M., & Fernald, L. C. H. (2016). Agricultural interventions for improved nutrition: A review of livelihood and environmental dimensions. *Global Food Security*, 8, 39–47.
- Fischhendler, I., Boymel, D., & Boykoff, M. T. (2016). How competing securitized discourses over land appropriation are constructed: The promotion of solar energy in the Israeli Desert. *Environmental Communication*, 10, 147–168.
- Frelat, R., Lopez-Ridaura, S., Giller, K. E., Herrero, M., Douxchamps, S., Djurfeldt, A. A., et al. (2016). Drivers of household food availability in Sub-Saharan Africa based on big data from small farms. *Proceedings of the National Academy of Sciences*, 113, 458–463.
- Gebregziabher, G., Villholth, K. G., Hanjra, M. A., Yirga, M., & Namara, R. E. (2013). Cost-benefit analysis and ideas for cost sharing of groundwater irrigation: Evidence from north-eastern Ethiopia. *Water International*, 38, 852–863.
- Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., et al. (2014). World population stabilization unlikely this century. *Science*, 346, 234–237.
- Giordano, M. (2009). Global groundwater? Issues and solutions. *Annual Review of Environment and Resources*, 34, 153–178.
- Giordano, M., Turrall, H., Scheierling, S. M., Tréguer, D. O., & McCornick, P. G. (2017). *Beyond 'more crop per drop'* (Research Report 169). Colombo, Sri Lanka: International Water Management Institute (IWMI); Washington, DC: The World Bank.
- Gollin, D., Jedwab, R., & Vollrath, D. (2016). Urbanization with and without industrialization. *Journal of Economic Growth*, 21, 35–70.
- GoM. (2013). Urban structure plan of Lilongwe City. Lilongwe, Malawi: Government of Malawi (GoM).
- Grewal, S. S., & Grewal, P. S. (2012). Can cities become self-reliant in food? *Cities*, 29, 1–11.
- Grey, D., & Sadoff, C. W. (2007). Sink or swim? Water security for growth and development. *Water Policy*, 9, 545–571.
- Hagos, F., & Mamo, K. (2014). Financial viability of groundwater irrigation and its impact on livelihoods of smallholder farmers: The case of eastern Ethiopia. *Water Resources and Economics*, 7, 55–65.
- Hagos, F., Mulugeta, A., Erkossa, T., Langan, S., Lefore, N., & Abebe, Y. (2017). Poverty profiles and nutritional outcomes of using spate irrigation in Ethiopia. *Irrigation and Drainage*.

- Hanjra, M. A., & Culas, R. J. (2011). The political economy of maize production and poverty reduction in Zambia: Analysis of the last 50 years. *Journal of Asian and African Studies*, 46, 546–566.
- Hanjra, M. A., & Gichuki, F. (2008). Investments in agricultural water management for poverty reduction in Africa: Case studies of Limpopo, Nile, and Volta river basins. *Natural Resources Forum*, 32, 185–202.
- Hanjra, M. A., Ferede, T., & Gutta, D. G. (2009a). Pathways to breaking the poverty trap in Ethiopia: Investments in agricultural water, education, and markets. *Agricultural Water Management*, 96, 1596–1604.
- Hanjra, M. A., Ferede, T., & Gutta, D. G. (2009b). Reducing poverty in Sub-Saharan Africa through investments in water and other priorities. *Agricultural Water Management*, 96, 1062–1070.
- Hanjra, M. A., Blackwell, J., Carr, G., Zhang, F., & Jackson, T. M. (2012). Wastewater irrigation and environmental health: Implications for water governance and public policy. *International Journal of Hygiene and Environmental Health*, 215, 255–269.
- Hanjra, M. A., Drechsel, P., Mateo-Sagasta, J., Otoo, M., & Hernandez-Sancho, F. (2015a). Assessing the finance and economics of resource recovery and reuse solutions across scales (Chap. 7). In P. Drechsel, M. Qadir, & D. Wichelns (Eds.), *Wastewater: Economic asset in an urbanizing world*. Dordrecht, Heidelberg, New York, London: Springer.
- Hanjra, M. A., Drechsel, P., Wichelns, D., & Qadir, M. (2015b). Transforming urban wastewater into an economic asset: Opportunities and challenges (Chap. 14). In P. Drechsel, M. Qadir, & D. Wichelns (Eds.), *Wastewater: Economic asset in an urbanizing world*. Dordrecht, Heidelberg, New York, London: Springer.
- Hanjra, M. A., Kayumbe, J. R. L., Barron, J., & Williams, T. (2016a, January). *Drivers of successful small scale irrigation schemes in Tanzania* (Draft Report). IWMI/WLE project on Small Scale Irrigation Schemes in Sub-Saharan Africa. Colombo, Sri Lanka: International Water Management Institute.
- Hanjra, M. A., Zawe, C., Barron, J., & Williams, T. (2016b, January). *Public private partnership investments in irrigation and sustainable agricultural water management solutions, Zimbabwe* (Draft Report). IWMI/WLE project on Small Scale Irrigation Schemes in Sub-Saharan Africa. Colombo, Sri Lanka: International Water Management Institute.
- Hanjra, M. A., Drechsel, P., & Masundire, H. M. (2017a). Urbanization, water quality and water reuse in the Zambezi river basin (Chap. 7). In J. Lautze, Z. Phiri, & V. Smakhtin (Eds.), *Zambezi river basin: Water and sustainable development*. New York: Earthscan; Colombo: IWMI (Forthcoming).
- Hanjra, M. A., Lydecker, M., Drechsel, P., & Paul, J. (2017b). Rural-urban food and nutrient dynamics and nutrient recovery from waste in developing countries. In J. Zeunert & T. Waterman (Eds.), *The Routledge handbook of landscape and food*. Routledge: London, UK, New York, NY.
- Hanjra, M. A., Noble, A., Langan, S., & Lautze, J. (2017c). Feeding the 10 billion within the sustainable development goals framework (Chap. 2). In I. J. Gordon, H. H. T. Prins, & G. R. Squire (Eds.), *Food production and nature conservation: Conflicts and solutions*. London, UK, New York, NY: Earthscan (Routledge).
- Hanjra, M. A., Qadir, M., & Drechsel, P. (2017d). Cross-sectoral resource recovery and reuse in Asia and Africa: Opportunities for a circular metabolism. In W. Montasser (Ed.), *Springer book series: RESILIENT CITIES: Re-thinking Urban Transformation: Circular urban metabolism: Generating co-benefits through urban resilience transition*. London, UK: Springer (Forthcoming).
- Hanjra, M. A., Wichelns, D., & Drechsel, P. (2017e). Investing in water management in rural and urban landscapes to achieve and sustain global food security. In J. Zeunert & T. Waterman (Eds.), *The Routledge handbook of landscape and food*. Routledge: London, UK, New York, NY.
- Headey, D. D., & Jayne, T. S. (2014). Adaptation to land constraints: Is Africa different? *Food Policy*, 48, 18–33.
- Holm, R., Wanda, E., Kasulo, V., & Gwayi, S. (2014). Identification of the potential opportunities, barriers, and threats within the sector in taking up sanitation as a business: Rural sanitation in Nkhata Bay District (Malawi). *Waterlines*, 33, 269–274.

- Hosu, S. Y., Cishe, E., & Luswazi, P. (2016). Vulnerability to climate change in the Eastern Cape province of South Africa: What does the future holds for smallholder crop farmers? *Agrekon*, 55, 133–167.
- Hussain, I., & Hanjra, M. A. (2003). Does irrigation water matter for rural poverty alleviation? Evidence from South and South-East Asia. *Water Policy*, 5, 429–442.
- Hussain, I., & Hanjra, M. A. (2004). Irrigation and poverty alleviation: Review of the empirical evidence. *Irrigation and Drainage*, 53, 1–15.
- IFAD. (2011). *Rural poverty report 2011* [Online]. International Fund for Agricultural Development (IFAD).
- Im, E.-S., Marcella, M. P., & Eltahir, E. A. B. (2014). Impact of potential large-scale irrigation on the West African monsoon and its dependence on location of irrigated area. *Journal of Climate*, 27, 994–1009.
- Jayne, T. S., Chamberlin, J., & Headey, D. D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy*, 48, 1–17.
- Kamwamba-Mtethiwa, J., Weatherhead, K., & Knox, J. (2016). Assessing performance of small-scale pumped irrigation systems in Sub-Saharan Africa: Evidence from a systematic review. *Irrigation and Drainage*, 65, 308–318.
- Katic, P. G., Namara, R. E., Hope, L., Owusu, E., & Fujii, H. (2013). Rice and irrigation in West Africa: Achieving food security with agricultural water management strategies. *Water Resources and Economics*, 1, 75–92.
- Keats, S., & Wiggins, S. (2017). *Future diets: Implications for agriculture and food prices* (Cancer/ODI Report). London, UK.
- Kihila, J., Mtei, K., & Njau, K. (2014). Wastewater treatment for reuse in urban agriculture; the case of Moshi Municipality, Tanzania. *Physics and Chemistry of the Earth*, 72, 104–110.
- Kurosaki, T. (2003). Specilization and diversification in agricultural transformation: The case of West Punjab, 1903–1992. *American Journal of Agricultural Economics*, 85, 372–386.
- Lejars, C., Daoudi, A. & Amichi, H. (2017). The key role of supply chain actors in groundwater irrigation development in North Africa. *Hydrogeology Journal* 25, 1593–1606.
- Lankford, B. (2009). Viewpoint—The right irrigation? Policy directions for agricultural water management in Sub-Saharan Africa. *Water Alternatives*, 2, 476–480.
- Larson, D. F., Muraoka, R., & Otsuka, K. (2016). Why African rural development strategies must depend on small farms. *Global Food Security*, 10, 39–51.
- Leah, H. S., James, S. G., Navin, R., Mario, H., & Paul, C. W. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11, 124010.
- Lee-Smith, D. (2010). Cities feeding people: An update on urban agriculture in equatorial Africa. *Environment and Urbanization*, 22, 483–499.
- Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., et al. (2013). Framing sustainability in a telecoupled world. *Ecology and Society*, 18.
- Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development*.
- Lydecker, M., & Drechsel, P. (2010). Urban agriculture and sanitation services in Accra, Ghana: The overlooked contribution. *International Journal of Agricultural Sustainability*, 8, 94–103.
- Magombeyi, M. S., Taigbenu, A. E., & Barron, J. (2016). Rural food insecurity and poverty mappings and their linkage with water resources in the Limpopo River Basin. *Physics and Chemistry of the Earth, Parts A/B/C*, 92, 20–33.
- Makoni, F. S., Thekiso, O. M. M., & Mbat, P. A. (2016). Urban wastewater for sustainable urban agriculture and water management in developing countries. In T. Younos & T. E. Parece (Eds.), *Sustainable water management in urban environments*. Cham: Springer International Publishing.
- Maziya, M., Mudhara, M., & Chitja, J. (2017). What factors determine household food security among smallholder farmers? Insights from Msinga, KwaZulu-Natal, South Africa. *Agrekon*, 56, 40–52.

- Miller, R. L., Anu, R., & Priyanie, A. (2017). Wastewater treatment and reuse in urban agriculture: Exploring the food, energy, water, and health nexus in Hyderabad, India. *Environmental Research Letters*, *12*, 075005.
- Mishra, A. K., Khanal, A. R., & Mohanty, S. (2017). Gender differentials in farming efficiency and profits: The case of rice production in the Philippines. *Land Use Policy*, *63*, 461–469.
- Moyo, T., & Machethe, C. L. (2016). The relationship between smallholder irrigation and household food availability and dietary diversity in Greater Tzaneen Municipality of Limpopo Province, South Africa. *Journal of Sustainable Development*, *9*, 165–178.
- Msilimba, G., & Wanda, E. M. M. (2012). *Wastewater production, treatment, and use in Malawi*. Luwanga, Mzuzu, Malawi: Water and Sanitation Centre of Excellence.
- Muchara, B., Ortmann, G., Mudhara, M., & Wale, E. (2016). Irrigation water value for potato farmers in the Mooi River Irrigation Scheme of KwaZulu-Natal, South Africa: A residual value approach. *Agricultural Water Management*, *164*(Part 2), 243–252.
- Mutengu, S., Hoko, Z., & Makoni, F. S. (2007). An assessment of the public health hazard potential of wastewater reuse for crop production. A case of Bulawayo city, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, *32*, 1195–1203.
- Namara, R. E., Awuni, J. A., Barry, B., Giordano, M., Hope, L., Owusu, E. S., et al. (2011). *Smallholder shallow groundwater irrigation development in the upper east region of Ghana* (Research Report 134). Colombo, Sri Lanka: International Water Management Institute.
- Nelson, M. C., Ingram, S. E., Dugmore, A. J., Streeter, R., Peeples, M. A., McGovern, T. H., et al. (2016). Climate challenges, vulnerabilities, and food security. *Proceedings of the National Academy of Sciences*, *113*, 298–303.
- Nicol, A., Langan, S., Victor, M., & Gonsalves, J. (2015). *Water-smart agriculture in East Africa* (352 pp). Colombo, Sri Lanka: International Water Management Institute (IWMI); CGIAR Research Program on Water, Land and Ecosystems (WLE); Kampala, Uganda: Global Water Initiative East Africa (GWI EA).
- Nonvide, G. M. A., Sarpong, D. B., Kwadzo, G. T. M., Anim-Somuah, H., & Amoussouga Gero, F. (2017). Farmers' perceptions of irrigation and constraints on rice production in Benin: A stakeholder-consultation approach. *International Journal of Water Resources Development*, 1–21.
- Olayide, O. E., Tetteh, I. K., & Popoola, L. (2016). Differential impacts of rainfall and irrigation on agricultural production in Nigeria: Any lessons for climate-smart agriculture? *Agricultural Water Management*, *178*, 30–36.
- Olney, D. K., Pedehombga, A., Ruel, M. T., & Dillon, A. (2015). A 2-year integrated agriculture and nutrition and health behavior change communication program targeted to women in Burkina Faso reduces anemia, wasting, and diarrhea in children 3–12.9 months of age at baseline: A cluster-randomized controlled trial. *The Journal of Nutrition*, *145*, 1317–1324.
- Oni, S. A., Maliwichi, L. L., & Obadire, O. S. (2011). Assessing the contribution of smallholder irrigation to household food security, in comparison to dryland farming in Vhembe district of Limpopo province, South Africa. *African Journal of Agricultural Research*, *6*, 2188–2197.
- Otoo, M., & Drechsel, P. (Eds.). (2017). *Resource recovery from waste: Business models for energy, nutrients and water reuse in low- and middle-income countries*. Earthscan (in press).
- Owens, G. R. (2016). 'We are not farmers': Dilemmas and prospects of residential suburban cultivators in contemporary Dar es Salaam, Tanzania. *Journal of Modern African Studies*, *54*, 443–467.
- Pandey, V. L., Mahendra Dev, S., & Jayachandran, U. (2016). Impact of agricultural interventions on the nutritional status in South Asia: A review. *Food Policy*, *62*, 28–40.
- Pavelic, P., Brindha, K., Amarnath, G., Eriyagama, N., Muthuwatta, L., Smakhtin, V., et al. (2015). *Controlling floods and droughts through underground storage: From concept to pilot implementation in the Ganges River Basin* (IWMI Research Report 165) (33 pp). Colombo, Sri Lanka: International Water Management Institute (IWMI). <https://doi.org/10.5337/2016.200>.
- Pingali, P. (2007). Westernization of Asian diets and the transformation of food systems: Implications for research and policy. *Food Policy*, *32*, 281–298.

- Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, 109, 12302–12308.
- Pingali, P. (2015). Agricultural policy and nutrition outcomes—Getting beyond the preoccupation with staple grains. *Food Security*, 7, 583–591.
- Rapsomanikis, G. (2015). Small farms big picture: Smallholder agriculture and structural transformation. *Development*, 58, 242–255.
- Richts, A., & Vrba, J. (2016). Groundwater resources and hydroclimatic extremes: Mapping global groundwater vulnerability to floods and droughts. *Environmental Earth Sciences*, 75, 1–15.
- Ricker-Gilbert, J., Jumbe, C., & Chamberlin, J. (2014). How does population density influence agricultural intensification and productivity? Evidence from Malawi. *Food Policy*, 48, 114–128.
- Riesgo, L., Louhichi, K., Gomez y Paloma, S., Hazell, P., Ricker-Gilbert, J., Wiggins, S., et al. (2016). *Food and nutrition security and role of smallholder farms: Challenges and opportunities—Workshop proceedings*. Seville, Spain: European Commission Joint Research Centre. <https://doi.org/10.2791/653314>.
- Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., et al. (2016). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, 1–14.
- Rodrik, D. (2016). Premature deindustrialization. *Journal of Economic Growth*, 21, 1–33.
- Sadoff, C. W., Hall, J. W., Grey, D., Aerts, J. C. J. H., Ait-Kadi, M., Brown, C., et al. (2015). *Securing water, sustaining growth: Report of the GWP/OECD task force on water security and sustainable growth* (180 pp). Oxford, UK: University of Oxford.
- Sahn, D. E., & Younger, S. D. (2017). The incidence of child health improvements. *Review of Development Economics*, 21, 304–320.
- Salami, A., Kamara, A. B., & Brixiova, Z. (2010). *Smallholder agriculture in East Africa: Trends, constraints and opportunities* (African Development Bank Working Paper). Tunis, Tunisia.
- Samson, S., Mdegela, R. H., Permin, A., Mlangwa, J. E., & Mahonge, C. P. (2017). Obstacles to low quality water irrigation of food crops in Morogoro, Tanzania. *Journal of Sustainable Development*, 10, 1.
- Scanlon, B. R., & Vladimir, S. (2016). Focus on water storage for managing climate extremes and change. *Environmental Research Letters*, 11, 120208.
- Schmidt, S., Magigi, W., & Godfrey, B. (2015). The organization of urban agriculture: Farmer associations and urbanization in Tanzania. *Cities*, 42(Part B), 153–159.
- Schoneveld, G. C. (2014). The geographic and sectoral patterns of large-scale farmland investments in Sub-Saharan Africa. *Food Policy*, 48, 34–50.
- Shah, T., Verma, S., & Durga, N. (2014). Karnataka's smart, new solar pump policy for irrigation. *Economic & Political Weekly*, 49, 11.
- Sheahan, M., & Barrett, C. B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, 67, 12–25.
- Shinkai, N., Sawada, Y., Hussain, I., Hanjra, M. A., Thrikawala, S., & Wijeratne, D. (2007). *Impact of irrigation infrastructure development on dynamics of incomes and poverty: Econometric evidence using panel data from Sri Lanka* (JBIC Research Paper No. 32) [Online]. Tokyo, Japan: Japan Bank for International Cooperation. Online at: <http://www.jbic.go.jp/english/research/report/paper/index.php>.
- Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences*, 112, 10657–10662.
- Sidibé, Y., & Williams, T. O. (2016). Agricultural land investments and water management in the Office du Niger, Mali: Options for improved water pricing. *Water International*, 41, 738–755.
- Sinyolo, S., Mudhara, M., & Wale, E. (2014). The impact of smallholder irrigation on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa. *Water SA*, 40.
- Smith, A., Snapp, S., Chikowo, R., Thorne, P., Bekunda, M., & Glover, J. (2017). Measuring sustainable intensification in smallholder agroecosystems: A review. *Global Food Security*, 12, 127–138.

- Tamene, S., & Megento, T. L. (2017). The effect of rural road transport infrastructure on small-holder farmers' agricultural productivity in Horro Guduru Wollega Zone, Western Ethiopia. *AUC Geographica*, 52, 79–89.
- Taylor, R. G., Scanlon, B., Doll, P., Rodell, M., van Beek, R., Wada, Y., et al. (2013). Ground water and climate change. *Nature Climate Change*, 3, 322–329.
- Tedesco, C., Petit, C., Billen, G., Garnier, J., & Personne, E. (2017). Potential for recoupling production and consumption in peri-urban territories: The case-study of the Saclay plateau near Paris, France. *Food Policy*, 69, 35–45.
- Thebo, A. L., Drechsel, P., Lambin, E. F., & Nelson, K. L. (2017). A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. *Environmental Research Letters*, 12, 074008.
- Timmer, C. P. (2017). Food security, structural transformation, markets and government policy. *Asia & the Pacific Policy Studies*, 4, 4–19.
- Unver, O., Wahaj, R., Lorenzon, E., Mohammedi, K., Osias, J. R., Reinders, F., et al. (2016). *Key and smart actions to alleviate hunger and poverty through irrigation and drainage* (FAO/ICID Background Paper). Online at: http://www.icid.org/wif2_bg_pap_st3.pdf.
- van Averbeke, W., Denison, J., & Mkeni, P. (2011). Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission. *Water SA*, 37, 797–808.
- van Ittersum, M. K., van Bussel, L. G. J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., et al. (2016). Can Sub-Saharan Africa feed itself? *Proceedings of the National Academy of Sciences*, 113, 14964–14969.
- Verdier-Chouchane, A., & Boly, A. (2017). Introduction: Challenges to Africa's agricultural transformation—Special issue paper. *African Development Review*, 29, 75–77.
- Vermeulen, S. J., Challinor, A. J., Thornton, P. K., Campbell, B. M., Eriyagama, N., Vervoort, J. M., et al. (2013). Addressing uncertainty in adaptation planning for agriculture. *Proceedings of the National Academy of Sciences*, 110, 8357–8362.
- Villholth, K. G. (2013). Groundwater irrigation for smallholders in Sub-Saharan Africa—A synthesis of current knowledge to guide sustainable outcomes. *Water International*, 38, 369–391.
- Villholth, K. G., Tøttrup, C., Stendel, M., & Maherry, A. (2013). Integrated mapping of groundwater drought risk in the Southern African Development Community (SADC) region. *Hydrogeology Journal*, 21, 863–885.
- Ward, F. A., Amer, S. A., & Ziaee, F. (2013). Water allocation rules in Afghanistan for improved food security. *Food Security*, 5, 35–53.
- Webb, P., & Block, S. (2012). Support for agriculture during economic transformation: Impacts on poverty and undernutrition. *Proceedings of the National Academy of Sciences*, 109, 12309–12314.
- Weldesilassie, A. B., Boelee, E., Drechsel, P., & Dabbert, S. (2011). Wastewater use in crop production in peri-urban areas of Addis Ababa: Impacts on health in farm households. *Environment and Development Economics*, 16, 25–49.
- Wichelns, D. (2014). Investing in small, private irrigation to increase production and enhance livelihoods. *Agricultural Water Management*, 131, 163–166.
- Wiggins, S., Kirsten, J., & Llambí, L. (2010). The future of small farms. *World Development*, 38, 1341–1348.
- Williams, T. O. (2015). Reconciling food and water security objectives of MENA and Sub-Saharan Africa: Is there a role for large-scale agricultural investments? *Food Security*, 7, 1199–1209.
- Williams, T. O., Gyampoh, B., Kizito, F., & Namara, R. (2012). Water implications of large-scale land acquisitions in Ghana. *Water Alternatives*, 5, 243–265.
- Woodhouse, P., Veldwisch, G. J., Venot, J.-P., Brockington, D., Komakech, H., & Manjichi, A. (2017). African farmer-led irrigation development: Re-framing agricultural policy and investment? *The Journal of Peasant Studies*, 44, 213–233.
- World Bank. (2008). *World development report 2008: Agriculture for development*. Washington, DC: The World Bank.
- World Bank. (2018). *Poverty and shared prosperity 2018: Piecing together the poverty puzzle*. Washington, DC: The World Bank.

- Zeweld, W., Huylenbroeck, G. V., Hidgot, A., Chandrakanth, M. G., & Speelman, S. (2015). Adoption of small-scale irrigation and its livelihood impacts in northern Ethiopia. *Irrigation and Drainage*, 64, 655–668.
- Zeza, A., & Tasciotti, L. (2010). Urban agriculture, poverty, and food security: Empirical evidence from a sample of developing countries. *Food Policy*, 35, 265–273.

Munir A. Hanjra was an economist at the International Water Management Institute, based at the Southern Africa regional office in Pretoria, South Africa. He sadly passed away during the preparation of this book. He previously worked as a senior research fellow (climate change and water policy) at the Charles Sturt University (CSU) and the Commonwealth Scientific and Industrial Research Organisation, Australia. He had over 20 years of professional experience on issues related to water and food security, including water sector investments for poverty reduction, global and regional water scarcity, water quality and sustainable development issues. Dr. Hanjra was involved in research and development programmes on water, land, agriculture and the environment in Australia, China, Canada, South and South East Asia, and East, West and Southern Africa. He has more than 100 publications, including 40 scientific research papers in peer-reviewed journals, and has made numerous other professional contributions. Research interests included water and food security, the water–food–energy nexus, resource recovery and reuse for improving food security and ecosystem health, ecosystem resilience and water sector adaptations to climate change with a focus on food security and sustainable development goals.

Timothy O. Williams recently retired as Director for Africa at the International Water Management Institute (IWMI). His professional work has focused on assisting smallholder farmers in developing countries to address the challenges they face in managing land and water resources to improve agricultural productivity and food security in an environmentally friendly manner, and in advising governments on growth-enhancing agricultural policies. He has worked at field level with smallholder farmers and at national level with decision makers in more than 12 English and French speaking countries in Africa and 6 Small Island Developing States in the Caribbean and the South Pacific. Tim holds a doctorate degree in agricultural economics from Oxford University. He is an Honorary Fellow of the Association of African Agricultural Economists and previously served on the editorial advisory board of the African Journal of Agricultural and Resource Economics.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

