IRRIGATION AND DRAINAGE
Irrig. and Drain. **67**: 60–71 (2018)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.2225

KEY AND SMART ACTIONS TO ALLEVIATE HUNGER AND POVERTY THROUGH IRRIGATION AND DRAINAGE[†‡]

OLCAY UNVER[1], ROBINA WAHAJ[2]*, ELISA LORENZON[3], KOUROSH MOHAMMADI[4], JEROME R. OSIAS[5], FELIX REINDERS[6], SUHAS WANI[7], JYOTSANA CHUCHRA[8], PETER LEE[9] AND I.M. SANGJUN[10]

[1]*Food and Agriculture Organization of the United Nations (FAO), Rome, Italy*
[2]*Food and Agriculture Organization of the United Nations (FAO), Islamabad, Pakistan*
[3]*Consultant, Turin, Italy*
[4]*University of Guelph, Guelph, Ontario, Canada*
[5]*National Irrigation Administration, Quezon City, Metro Manila, the Philippines*
[6]*Institute for Agricultural Engineering (ARC-IAE), Silverton, South Africa*
[7]*International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Patancheru, Hyderabad, India*
[8]*Geospatial Media and Communications, Noida, Uttar Pradesh, India*
[9]*President Hon., ICID, Stretham, Ely, United Kingdom (UK)*
[10]*Seoul National University, Seoul, Republic of Korea*

ABSTRACT

In the pursuit of information to support policies and actions to alleviate hunger and poverty through irrigation and drainage, this paper attempts to provide correlations between water scarcity, communities and poverty. Many reviews have found strong direct and indirect relationships between irrigation and poverty. One of the main goals of the international community is to eliminate hunger and poverty and in this perspective, through the Millennium Development Goals, much progress has been achieved and evidence obtained. Sustainable Development Goals and various other United Nations initiatives intend to move forward this agenda by making it a part of broader development frameworks. In this paper, the important elements of irrigation and drainage that affect the alleviation of hunger and poverty are discussed. These elements are grouped into governance, rights-based developments, water rights and pricing, management, efficiency improvement, and the role of technology. Both the potential and the need for innovative technology and solutions in irrigation are underlined, which can be used to cater for the challenges in different subsectors. The main focus of these solutions is on maximizing productivity and efficiency, reducing water losses, achieving sustainable intensification and managing demands on water resources and the associated trade-offs. Copyright © 2018 John Wiley & Sons, Ltd.

KEY WORDS: irrigation and drainage management; water management to alleviate hunger and poverty; irrigation modernization; water scarcity; poverty and hunger

Received 26 December 2017; Accepted 26 December 2017

RÉSUMÉ

Dans l'effort constant de soutenir l'information sur le sujet des politiques et des actions pour mettre en perspective le rôle et les impacts du drainage et de l'irrigation dans la lutte contre la faim et la pauvreté, ce papier a pour ambition de mettre en corrélation la rareté de l'eau, la population impactée et la pauvreté. De nombreuses publications montrent de solides relations directes ou indirectes entre l'irrigation et la pauvreté. L'élimination de la faim et de la pauvreté est l'un des principaux objectifs de la communauté internationale et c'est bien à travers les Objectifs du Millénaire pour le développement que les progrès les plus tangibles sont réalisés. Les Objectifs de développement durable et les initiatives des Nations Unies, parmi d'autres, ont l'intention de faire avancer ce programme en intégrant ces objectifs le plus largement possible dans l'encadrement du développement. Dans cet article, les auteurs discutent des éléments importants de l'irrigation et du drainage ayant un impact

*Correspondence to: Dr Robina Wahaj, Food and Agriculture Organization of the United Nations (FAO), Islamabad, Pakistan. E-mail: robina.wahaj@fao.org
[†]Actions clés et pertinentes pour atténuer la faim et la pauvreté par le moyen de l'irrigation et du drainage
[‡]This paper is based on the Background Paper of Sub-theme 3 *Key and smart actions to alleviate hunger and poverty through irrigation and draingage* of the 2nd World Irrigation Forum

sur la réduction de la faim et de la pauvreté. Ces éléments sont regroupés dans la gouvernance, le développement basé sur les droits, les droits de l'eau et la tarification, la gestion, l'amélioration de l'efficacité, et le rôle de la technologie. Le potentiel ainsi que la nécessité de faire usage de la technologie et des solutions d'irrigation innovantes sont soulignés, et être utilisé pour relever les défis des différents sous-secteurs. L'objectif principal de ces solutions est la maximisation de la productivité et de l'efficacité, la réduction des pertes d'eau, la réalisation de l'intensification durable et la gestion des demandes en ressources en eau et les compromis associés.

MOTS CLÉS: gestion de l'irrigation et du drainage; gestion de l'eau pour lutter contre la famine et la pauvreté; modernisation de l'irrigation; pénurie d'eau; pauvreté et faim

INTRODUCTION

Agriculture is expected to feed an estimated population of more than 9 billion by the year 2050 by means of a 60% increase over 2006 food production levels, with 80% of the increase stemming from intensification which is essentially possible under irrigation. At the same time, increasing water scarcity and demand for water resources from other sectors are putting unprecedented pressure on agriculture, which uses approximately 70% of the total water withdrawal worldwide, to release part of this water.

Internationally, food security has slowly, but markedly, improved during recent years. Approximately 842 million people today are estimated to be experiencing chronic hunger. The 2013 Global Food Security Index (Figure 1) provides a worldwide perspective on which countries are the most and least vulnerable to food insecurity.

Irrigated agriculture has been recognized as one of the most important components of world food security and specifically in the reduction of rural poverty. Irrigated agriculture uses some 20% of the total farmland in the world but produces 40% of the food.

Approximately 75% of poor people in developing countries live in rural areas. In these areas, agriculture is the main source of income. Access to adequate food in the rural areas of many developing countries depends heavily on access to natural resources, including water, that are necessary to produce food.

One of the sub-themes of the Second World Irrigation Forum, *Key and smart actions to alleviate hunger and poverty through irrigation and drainage*, focuses on the smart actions and use of innovative technology to provide the catalyst for broader aspects of agricultural development especially in least developed countries (LDCs) to alleviate poverty and hunger. The key is to adopt the 'right' actions and technology which enable users to innovate and adapt them to their circumstances. This background paper is intended to provide the basis for further discussion on these topics under three broad categories:

- water- and climate-smart approaches for sustainable smallholder agriculture;
- financing mechanisms for development and management of irrigation and drainage projects;

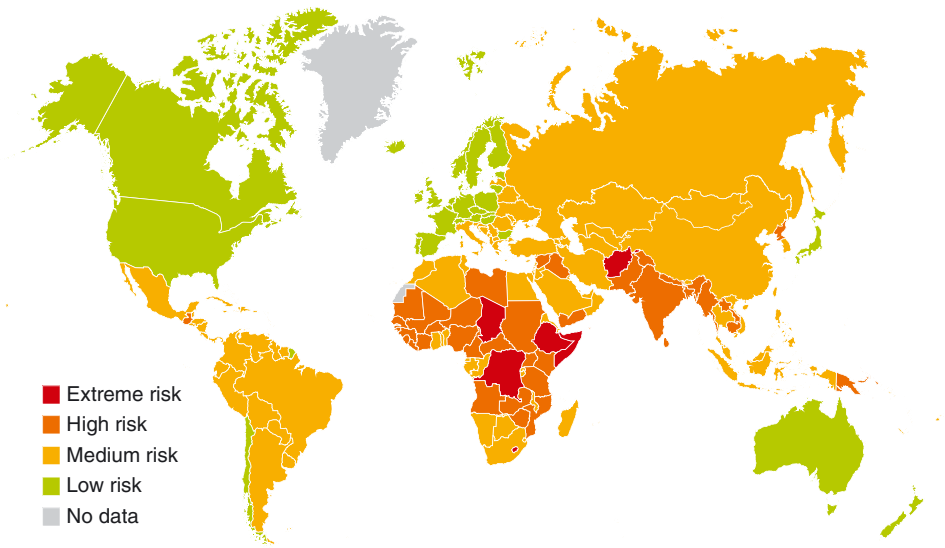

Figure 1. Food Security Index 2013 (The Economist Intelligence Unit Limited). [Colour figure can be viewed at wileyonlinelibrary.com]

- adaptation measures for rural water management for water and food security.

IRRIGATION AND POVERTY AND HUNGER LINKAGES

Many reviews have found strong direct and indirect relationships between irrigation and poverty (Hussain and Hanjra, 2004). The benefits of irrigation can be seen in higher production, higher yields, less reliance on weather conditions, lower risk, and increase in farming activity year-round. Landless farmers may benefit less in the short term, but enhancing productivity, increasing cultivated areas and providing adequate access to water create more job opportunities for landless farmers as well. Irrigated agriculture significantly contributes towards generating rural employment and maintaining rural livelihoods (Bhattarai *et al*., 2002).

The role of irrigation in the alleviation of poverty has been the focus of many international communities and groups in recent years. It is clear that more investment is going into the modernization of existing systems to improve the efficiency of water use and increase crop production. This approach can directly benefit farmers and alleviate poverty. It can also enhance the livelihoods of those who are not the primary beneficiaries (International Commission on Irrigation and Drainage (ICID), 2014). There are employment possibilities for the landless poor on larger farm units and in distributive trades, as well as in product processing.

Access to improved irrigation significantly contributes to rural poverty reduction through employment and livelihoods within a region. Indirect benefits, such as more stable rural employment as well as higher rural wage rates, help landless farm labourers obtain a significant share of the improved agricultural production (Chambers, 1988; Barker *et al*., 1999). Lower food grain prices benefit poor urban and rural landless communities more by enabling them to purchase required food items at affordable prices. Keeping food prices at relatively low levels also greatly assists the industrial sector to avoid the pressure of increasing the real wage rate. In this process, improved agriculture indirectly 'subsidizes' the industrial sector of the economy as well (ICID, 2014).

Irrigation enables smallholders to adopt more diversified cropping patterns, and to switch from low-value subsistence production to high-value market-oriented production. Increased production helps make food available and affordable for the poor. Climate change and variability link directly and indirectly to irrigation, through, for example, changes in rainfall patterns, increased scarcity, impacts on land and soil, and increased competition. Irrigation also provides a defence against droughts, which are predicted to occur more frequently. Irrigation played a vital role in the green revolution that took place in the twentieth century, which helped saved over a billion people from starvation in many countries, particularly in Asia and South America. However, since then irrigation has been blamed for being highly inefficient and for causing damage to the environment and ecosystems. Lack of drainage in many countries is causing waterlogging and salinity and is destroying otherwise fertile lands.

Irrigation development, it has been argued, has displaced marginal and poor farmers and have made them landless labourers, driving them to become urban dwellers in some regions (Chambers, 1988). However, the positive social and economic impacts of irrigation far outweigh some of these negative ones and can be compensated through improved planning, implementation and management of irrigation systems (Bhattarai *et al*., 2002), and broader safety nets for the urban poor.

As population growth and demand for water use in irrigation rapidly increase, the struggle for a secure water supply will become more difficult to administer, especially in arid parts of the world. Large arid areas suffer from absolute water scarcity which affects millions of people, many of whom are poor and underprivileged. It can be stated that there is a strong linkage between irrigation and drainage, and hunger and poverty alleviation, in which the poor benefit from well-managed irrigation through higher yields, lower risk of crop failure, adoption of diversified cropping patterns, increased high-value and market-oriented crop production, and fixed employment (Hussain and Hanjra, 2004).

Deliberations in the International Commission on Irrigation and Drainage (ICID) Task Force on the *Role of Irrigation in Poverty Alleviation and Livelihoods* can be summarized as:

- irrigation professionals need to be more sympathetic to the actions of the poor in making better use of irrigation systems to improve their circumstances (e.g. multiple use of canal banks for farm to market access);
- many of the poorest members of the community are not able to be farmers, or find their best opportunities in irrigated farming, or in agriculture at all;
- of those that remain in agriculture, most depend on rainfed cropping or become pastoralists, or may find other employment in towns;
- most irrigation schemes have multiple uses and these additional uses can provide opportunities for the poor, which may be non-agricultural but depend on irrigation development for water;
- the role of irrigation in poverty alleviation may be small in terms of simply providing water to grow crops,

but may be significant in enabling other uses of the infrastructure as well as adding to food security.

HISTORICAL DEVELOPMENT

From the 1970s to the 1990s, the government sector, with significant intervention by the international development banks, financed large irrigation projects that had strong positive effects on economic growth, benefiting the poor. In the late 1980s, it became difficult to justify new irrigation development costs due to declining crop prices and increasing development costs for new irrigation schemes. While on the one hand, financial capability has been lacking for new infrastructure as well as for modernizing and rehabilitating present structures, on the other hand, there has been an increase in private sector financing of large water-sector infrastructure, and small-scale irrigation systems with particular interest in groundwater development because of the private level of control they offer. Recently, in order to augment the performance of the irrigation sector, the possibility of involving the private sector through public–private partnerships (PPPs) has been explored and adopted with the financial support of development banks (i.e. the World Bank and the Asian Development Bank).

Despite the significant achievements in irrigated agriculture, water use for irrigation is still generally inefficient. On average, half of the water diverted or stored for irrigation evaporates or percolates into the ground without watering crops. Likewise, consumption for irrigation has lower economic value of water compared to industrial, municipal and domestic consumption. Thus there will be a natural tendency to reduce water allocation to agriculture in favour of other uses.

It is imperative to develop drastic improvements in irrigation to have a significant impact on poverty alleviation and ensure water allocation for agriculture while sustaining natural resources. Irrigation professionals have an important role in this aspect. They need to sufficiently recognize the multiple uses of water. Developing advanced methods and smart irrigation systems can reduce water consumption significantly and increase water efficiency. In recent years, the cost of technology has been reduced and it is now practical to use those technologies in farm management.

Generally, water shortages lead to several forms of cooperative association, especially in isolated farmworker societies. Since individual farmers could not manage to pay for all the equipment needed to divert or draw water, communities have developed centralized irrigation systems with specific rules for water distribution. Depending on the farmers' wealth and social status, a certain volume of water is allowed to flow onto their land. Irrigation has come a long way, from its foundation to the present situation where there is legitimate water distribution for all stakeholders. This should continue, and all improvements in irrigation should be geared towards equitable water distribution and poverty alleviation.

STATE OF THE ART

Water is an integral element to human food security. Water of sufficient quantity and quality is also essential for agricultural production but it is increasingly under stress (High Level Panel of Experts on Food Security and Nutrition (HLPE), 2015). Traditional surface irrigation practices have in the past been suitable for smallholders who are fortunate enough to have abundant low-cost supplies of water. However, the traditional practices smallholders use do not utilize water very efficiently in terms of crop yield per unit of the water applied (Ayele and Tedla, 2006). Since water is usually the most critical factor that directly affects crop production, it is critical that smallholders begin using more efficient water supply and irrigation technologies.

Finding the right technology is the main challenge and providing an appropriate and efficient irrigation system is not an easy task. It usually requires the development of low-cost and easy-to-operate systems. According to Amadei (2004), an appropriate technology is usually characterized as small-scale, energy efficient, environmentally sound, labour-intensive, and controlled by the local community. In addition to technology, reform in policies and water governance is also required to facilitate the access of poor communities to the irrigation water. The right to water does not justify subsidized water for irrigation, and proper use of water can increase the farmers' income and, in turn, they can pay for the services that they use.

Adapting agriculture to climate change on all fronts is essential for securing adequate and nutritious food for all. It is also a driver for, and is impacted by, technological change and innovation in a broader spectrum. This includes interventions for deforestation, land degradation and desertification, which result from overuse of natural resources and are exacerbated by climate change, creating, in return, negative impacts on the quantity and quality of reliably available water resources. Measures taken to cope with water scarcity will help alleviate the direct and long-term effects of desertification on land and soil quality, soil structure, organic matter and soil moisture, which collectively contribute to climate change adaptation and mitigation.

Climate-smart agriculture (CSA), as defined and presented by the Food and Agriculture Organization of the United Nations (FAO) at The Hague Conference on Agriculture, Food Security and Climate Change in 2010, addresses food security and climate challenges through three main pillars (FAO, 2013a):

- sustainably increasing agricultural productivity and incomes;
- adapting and building resilience to climate change;
- reducing and/or removing greenhouse gas emissions, where possible.

Water governance: A rights-based approach to water for food security

A recent report (HLPE, 2015) on food security and nutrition (FSN) describes the multiple interfaces between water and food security and nutrition (Figure 2).

It considers four dimensions of water—availability, stability, water quality and access. These dimensions are similar to the four dimensions of food security and are in line with the Sustainable Development Goals (SDGs), in particular, SDG 2: *End hunger, achieve food security and improved nutrition and promote sustainable agriculture* and SDG 6: *Ensure availability and sustainable management of water and sanitation for all*.

There have been both express and implied references to a right to water in public international law. Although human rights to food and clean water have been recognized by most countries, in reality access to these two basic rights has been elusive for millions of poor people in the LDCs. Inequity in access to food and to water is evident in the majority of the least developed and developing countries, in particular those that also suffer from water scarcity.

The HLPE has recognized the limitations of the widely used concept of integrated water resources management (IWRM) in addressing conflicts, suggesting that IWRM, while providing a comprehensive framework that can bring together economic, social and environmental objectives, is not well equipped to tackle implementation challenges at ground level. Instead, they recommend: sustainable ecosystem management and conservation to ensure continued availability, quality and stability of water for FSN; improving the resilience, water efficiency and water productivity of existing agricultural systems; and improving the governance of water for FSN, including promotion of a rights-based approach.

They refer to relevant guidelines and principles, such as the right to adequate food, the right to safe drinking water

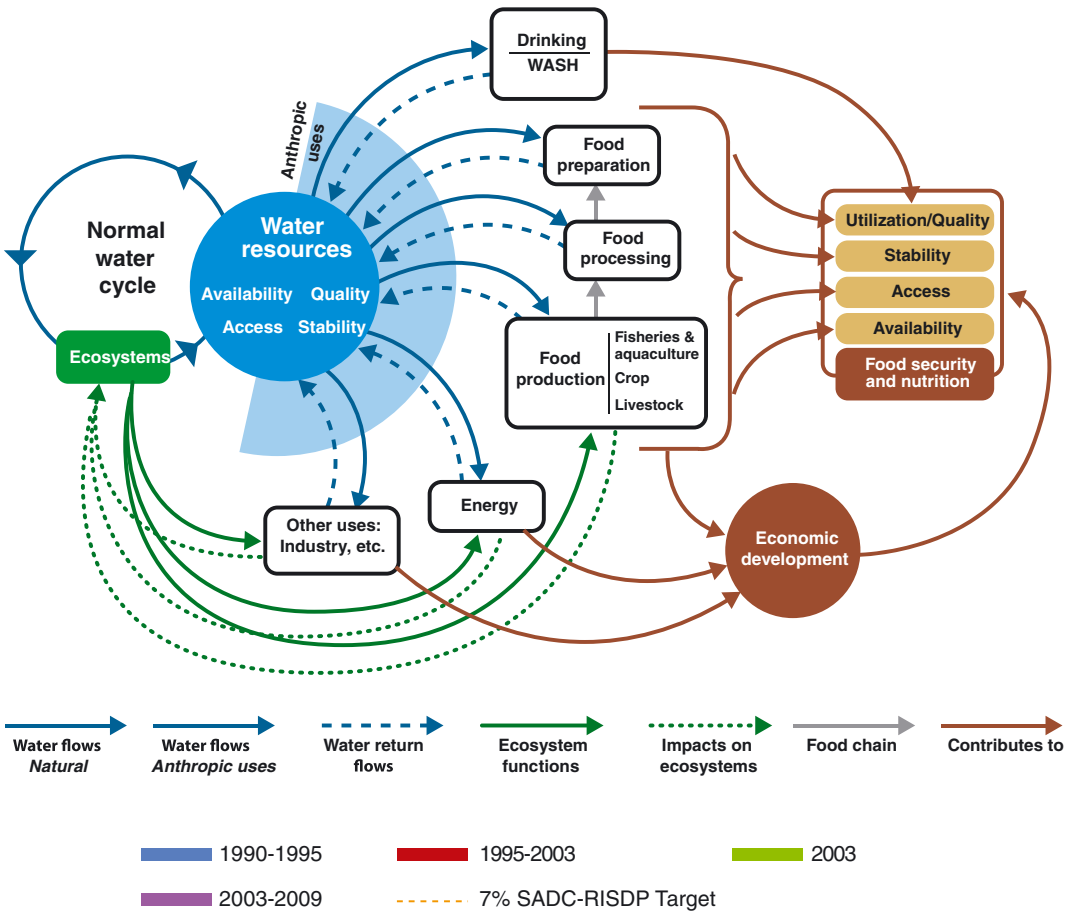

Figure 2. The multiple interfaces between water and food security and nutrition (HLPE, 2015). [Colour figure can be viewed at wileyonlinelibrary.com]

and sanitation, the Voluntary Guidelines for Security Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (VGSSF), and the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests (VGGT), to provide a basis for further action to safeguard water for FSN. Various tools for managing water scarcity and allocation are discussed, including water use authorization, tradable water permit systems, and water pricing (HLPE, 2015).

Institutions providing water services and those with a mandate to protect people's right to food and to water—not only for health and hygiene but for agricultural production as well—are failing and need to be inclusive instead of servicing only the influential and powerful few. People get access to water not only through formal water rights and institutions but informal arrangements also determine who gets access to water (FAO, 2016). In the context of increasingly formalized water rights, water tenure of vulnerable segments of the population—men and women—has to be strengthened and protected for them to have access to water for food production and for health, hygiene and sanitation.

Contrasting policies and competing uses of water from different sectors, coupled with the increasing impacts of climate change and variability, exacerbate water access issues and have a negative impact on efficiencies of resource use, particularly in water-scarce situations. It is extremely important to ensure coherence in policies on water, agriculture and food security in order to address issues impacting smallholders' access to water for agricultural production.

Allocation of water resources is one of the most important components of governance, especially in water-scarce situations. Different countries have different systems, rules and priorities for allocating water to different sectors and different uses at various scales—river basin, national, local. Ensuring water allocation for food production and for fulfilling basic needs of poor and marginalized populations is a big challenge, particularly when it is fairly difficult to assess the value of such allocations in monetary or economic terms. Water allocation in river basins that are shared by different countries or different administrative units is particularly challenging. The first step in good governance and water allocation is to carry out water accounting and understand not only the surface water fluxes but also interconnectedness of surface and groundwater.

Considering the multiple interfaces that water has with food security and the numerous stakeholders and actors involved with competing interests and uses, good governance of water resources is required for achieving SDG 6 and SDG 2. In particular, *enhanced governance of the irrigation and drainage* sector can go a long way in helping countries at national and local levels to achieve food security through providing poor and vulnerable men, women and children with equitable access to water for health and for 'wealth'—income generation.

Managing irrigation and drainage systems

Irrigation can help achieve food security; however, *expansion of irrigated agriculture* and water development are possible in some countries, especially in Africa. In most other contexts modernization of irrigation systems is the only way forward to achieve improved water productivity and therefore food security.

According to AQUASTAT—the largest online database of the FAO on water—in 2012 over 324 Mha (million hectares) were equipped for irrigation worldwide, of which about 85% or 275 million ha are actually irrigated. In many countries in Asia, North Africa, the Near East, western Europe, North and South America the irrigated area is up to 50% or more of the total cultivated area (Figure 3). This means that potential for expansion of the irrigated areas in these countries and regions is very limited.

However, sub-Saharan Africa is the region with the lowest percentage of the cultivated area that is irrigated, just over 3% against almost 21% at the global level. At the same time it has the highest prevalence of undernourishment (FAO, 2016).

In Africa there is a potential of 43 Mha that can be irrigated but only 13 Mha are presently under irrigation. Figure 4 shows the trends in the share of total cultivated area that was equipped with irrigation facilities in the South African Development Community (SADC) countries between 1990 and 2009 (FAO, 2016). It was found that throughout the SADC region, only 8% of the cultivated area was equipped with irrigation facilities. SADC member states need to take serious measures to increase investment in irrigation projects, in order to tap the potential of irrigation to increase agricultural productivity and food security, and reduce poverty.

Groundwater as a source of irrigation water accounts for about 40%—112 Mha out of total 275 Mha—of the total irrigation in the world (Global Water Partnership (GWP), 2012). In South Asia it accounts for more than 50% of the total irrigated area (Table I). In many countries, groundwater extraction has provided farmers, large and smallholders, with the opportunity to grow crops and use the water for other livelihood purposes—thanks to the availability of low-cost water-lifting technology. However, in many cases groundwater is not a renewable resource and is being depleted fast. Efforts need to be made to monitor groundwater use and changes in aquifers in order to sustainably use the resource.

The efficiency of irrigation schemes, predominantly surface irrigation schemes and systems, is rather low. Far too many irrigation schemes, in particular large-scale

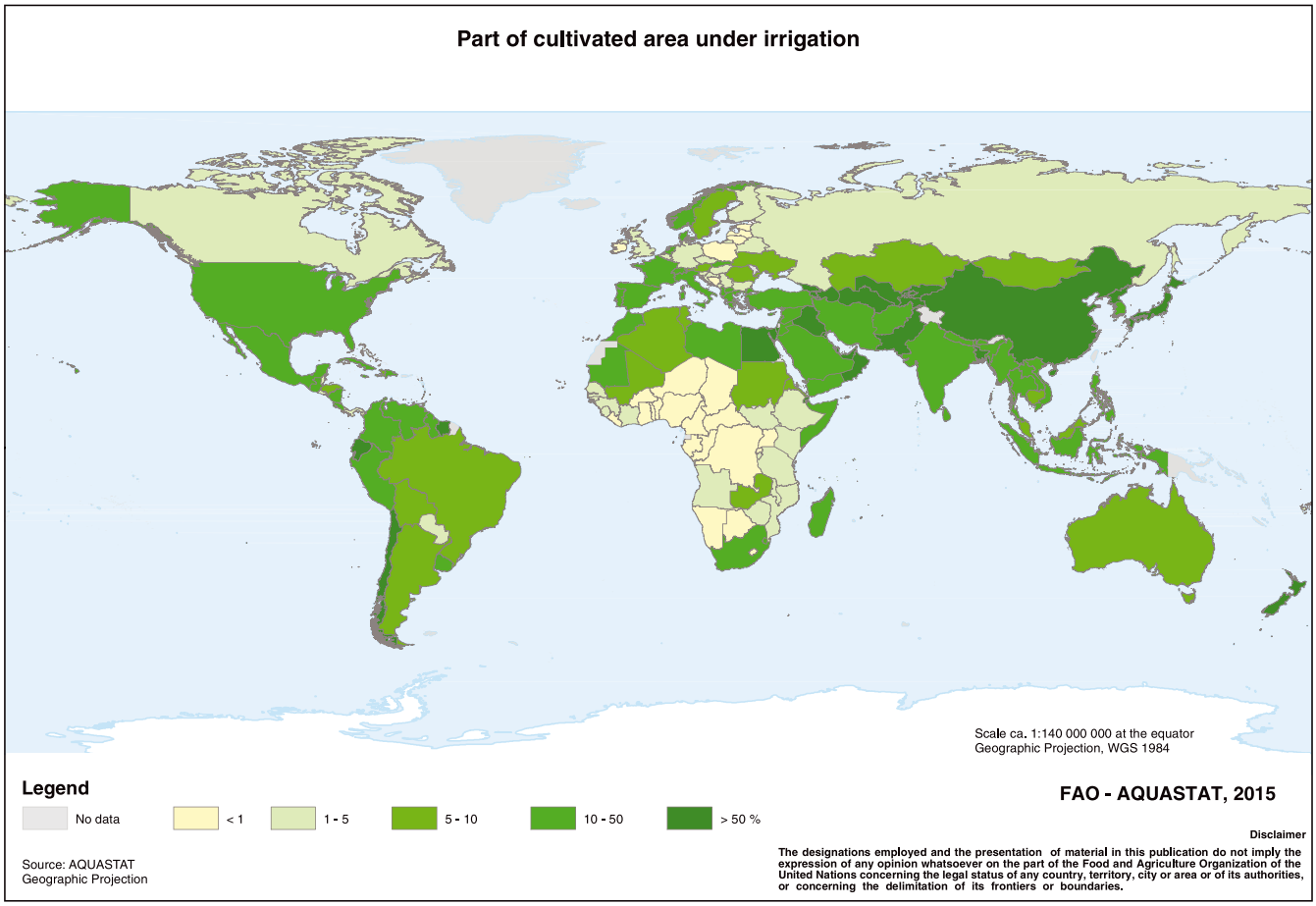

Figure 3. Area equipped with irrigation as percentage of cultivated area, 2012 (FAO, 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

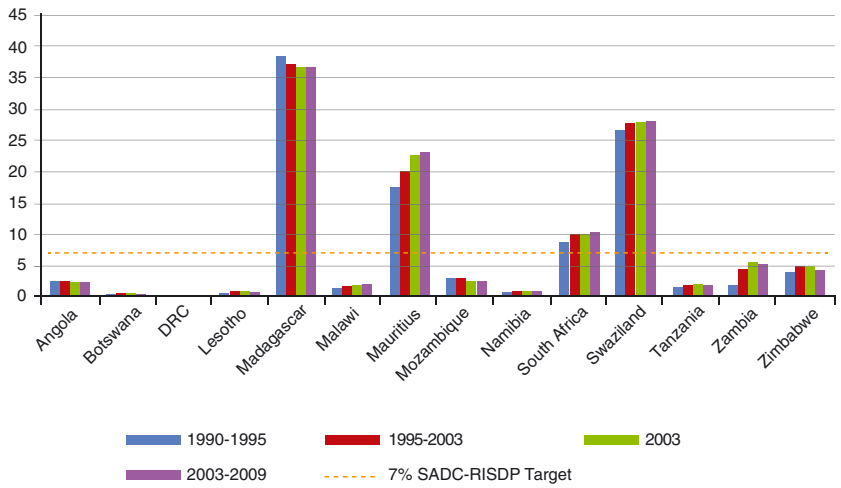

Figure 4. Percentage of cropland area equipped for irrigation in SADC countries, 1990–2009. (FAO, 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

irrigation systems, perform below their potential—their productivity levels and efficiencies are low and water delivery services to farmers and other water users are often neither reliable nor flexible. According to some FAO estimates, the average overall efficiency of irrigation schemes is 56%. Figure 5 shows a high potential for increase in efficiency in

Table I. Global survey of groundwater irrigation (GWP, 2012)

	Groundwater irrigation		Groundwater volume used	
	Mha	Proportional total (%)	km^3	Proportional total (%)
South Asia	48.3	57	262	57
East Asia	19.3	29	57	34
South East Asia	1.0	5	3	6
Middle East and NorthAfrica	12.9	43	87	44
Latin America	2.5	18	8	19
Sub-Saharan Africa	0.4	6	2	7
Global total	*113*	*38*	*545*	*43*

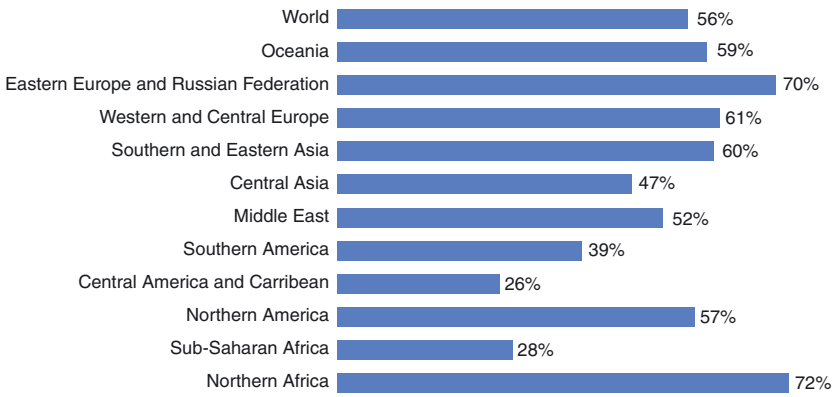

Figure 5. Irrigation scheme efficiencies (FAO, 2016). [Colour figure can be viewed at wileyonlinelibrary.com]

many parts of the world. Central Asia, the Middle East and southern and eastern Asia are particularly important as most parts of these regions also suffer from water scarcity.

Irrigated agriculture needs to perform better and with higher productivity and efficiency in order to feed the world and provide good livelihoods for farmers. This situation requires that the irrigated agriculture sector moves away from the 'business-as-usual' approach and adopts innovative, forward-looking and effective governance to do more with less water. It is even more important if the goal is to achieve a sustainable water- and food-secure future. This is also acknowledged in the white paper on *Towards a water and food secure future: critical perspectives for policy-makers* produced by the FAO and World Water Council for the high-level panel discussion at the Seventh World Water Forum (2015).

Technological and technical solutions to improve the efficiency and productivity of irrigation water are available, for example shifting, where appropriate, from low-efficiency surface irrigation to high-efficiency pressurized irrigation; lining of canals using appropriate technology, etc. These technologies and techniques are site- and condition-specific, and may not work if not accompanied by good operation and management. For these to be successful much needs to be done on the soft side—for example, capacity development of not only farmers but the whole chain of actors from decision makers to service providers to farmers.

FUTURE OUTLOOK

Poverty alleviation needs more attention and needs are rapidly changing, and irrigation is only one way to deal with it. In most cases, irrigation is not the most important means to deal with poverty, although some might believe so. To achieve true and working irrigation and drainage as a catalyst in poverty alleviation, the international community should be guided by the following objectives:

- increase the productivity of agriculture through effective and well-managed irrigation and drainage systems to meet the demands of a rapidly growing population with a finite land and water resources;
- for individual countries to prioritize agricultural self-sufficiency first before being part of the international market economy;
- revisit the existing design of drainage, dams and pertinent structures to be climate change resilient and at the same time environmentally sound;

- continue extensive research into innovative technology and solutions in irrigation.

In order to achieve global food and nutritional security, commitment and investment are needed (United Nations Department of Economic and Social Affairs (UNDESA), 2014) to:

- *produce more nutritious food with less water*. Innovative technologies are required to ensure greener and more sustainable food production. They are needed to improve crop yields; implement efficient irrigation strategies; reuse of drainage water and use of water resources of marginal quality; produce smarter ways to use fertilizer and water; improve crop protection; reduce post-harvest losses; and create more sustainable livestock and marine production;
- *focus on human capacities and the institutional framework*. Agricultural development in the LDCs lies mainly in the hands of smallholders, a large majority of whom are women. Therefore, new institutional arrangements are needed that centralize the responsibility for water regulation, yet decentralize water management responsibility and increase user ownership and participation;
- *improve the value chain*. From production, post-harvest handling, processing, retailing, consumption to distribution and trade, efficient water and food recycling strategies can be addressed. They can help secure environmental water requirements when reuse of treated water is not culturally acceptable for other uses.

Investing in irrigation and drainage

Investment in irrigation has dropped sharply since the 1980s. It is critical to understand the reasons behind that trend and react accordingly. It is crucial to show that the inefficiencies in irrigation management are—most of the time—fixable, and less severe than a limited rapid look may show when all aspects of the agricultural chain and multiples uses of water are considered.

For many developing countries, investment in irrigation will continue to represent a substantial share of investment in agriculture, but the pattern of investment will change substantially from previous decades. New investments will focus much more on enhancing the productivity of existing systems through:

- *investing in infrastructure*—large- and small-scale irrigation systems and small landholdings;
- *investing in institutions*—formal and informal;
- *investing in people*—capacities starting from basic education institutions to professional irrigation and drainage system managers to farmers to decision makers.

Modernization of existing infrastructure can lead to making better use of existing infrastructures and should be given priority. It should be based on current and future market prospects and water service needs rather than those needs for which the system was initially designed. Modernization requires serious funding, excellent training, a design that has envisioned how the project will operate on a minute-by-minute basis, deliberate and slow implementation, and great attention to detail. There are no quick, magical, solutions.

For many years the FAO has been carrying out a programme of 'modernization of irrigation management' with the aim of helping develop the capacity to assess and improve the performance of collective infrastructure management in the technical, managerial and institutional spheres, and how to develop modernization plans. It has yielded several standard products that are now widely used, such as the rapid appraisal procedure (RAP) for auditing, the MASSCOTE methodology for auditing and planning (FAO, 2007), and the MASSMUS methodology for assessing and modernizing management in the context of multiple uses of water (FAO, 2013b).

The key is the capacity first to tackle management performance in the right way, and second to improve it with appropriate approaches. While modernization represents a valid investment option in infrastructure, other investment opportunities will have to be considered. Where possible, agricultural water investments should be targeted at small landholdings in poor areas, and new irrigation projects should be designed with the needs and capabilities of the poor in mind. Promoting infrastructure and technologies adapted for smallholders is expected to have a positive impact on poverty reduction.

Investment in drainage will continue at relatively modest levels, although waterlogging and salinization problems resulting from past development will continue to require remediation. Thus, there will be considerable tension arising from these financial needs compared with governments' willingness and ability to finance them.

Investing in sound irrigation institutions ensures sustained returns on infrastructure investments and optimizes the allocation of water to irrigation, which affects the performance of the system and in some cultures defines its performance. Investing in institutions includes regulatory measures, transboundary agreements, water pricing, river basin management and devolution of responsibilities to farmers through water users' associations (WUAs). Institutions play an important role especially in those regions

Table II. Investing in irrigation and drainage—challenges and constraints.

Sector	Challenges and constraints
Water rights	Without well-defined rights to water, infrastructure repair suffers all the well-known problems of a common property resource, with little incentive for anyone to contribute their share of the financing (Herrera *et al*., 2006). A major challenge in formalizing water rights is to include traditional (often small) systems and to avoid disenfranchising established small-scale water users (Bruns and Meinzen-Dick, 2000).
Water management	The resulting risks for the environment and for society will require careful management. Growing water scarcity will have to be managed as well, with a strong need to further improve water productivity and strengthen the use of demand management approaches. In many river basins, intersectoral competition for water resources is a critical challenge that will need to be addressed.
Infrastructure subsidies	While subsidies might have a positive impact in promoting new technologies and modernizing the infrastructure, on the other hand, it might have negative impacts on water consumption. A study conducted by Brinegar and Ward (2009) demonstrated that subsidizing modern irrigation infrastructure, even when intended to promote water conservation, can increase consumption and reduce supplies available for use outside agriculture. In this case, shifting to drip irrigation induced farmers to select crops with higher ET and yield, increasing the total water need of the irrigated area.
Maintenance costs	Governments rarely assign high priority to using taxpayer resources to maintain irrigation infrastructure already built. A common belief held by governments is that even if they subsidize the development of irrigation initially, they are less willing to assign adequate budgets to keep infrastructure in top condition. Another belief is that farmers should pay for maintenance. Nevertheless, it has proved impossible to recover operating and maintenance costs from farmers, with the result that services have been underfunded and have deteriorated, and improvements in productivity and farmers' incomes have been below target. If systems are to deliver quality service, they have to be profitable enough for farmers to earn an adequate surplus, and arrangements for financing operation and maintenance costs have to be clear from the outset. The optimal arrangement is a farmer-managed scheme with full financial autonomy. If subsidies are required, they need to be transparent and reliable (World Bank, 2005).
Water charges	Water charges are fundamental to recovering capital costs, maintenance costs and making the project viable. However, it is very challenging to establish a fair and effective rate especially in poor areas, for several reasons such as: (i) water pricing must be based on measured deliveries. However, it is widely recognized that the applicability of volumetric water pricing to individual farms is limited to a small subset of technologically and managerially advanced irrigation schemes involving huge investments that cannot be afforded in poor areas and countries (International Water Management Institute (IWMI), 2007); (ii) low water charges can have a great benefit for farmer incomes but they can also negatively affect water saving because they increase consumption and discourage farmers from using water-saving crops. Low charges are not sufficient to recover maintenance and operation costs. On the other hand, high water charges might encourage water saving and cost recovery but might not be feasible for farmers, causing social and economic problems.
Water allocation	In the interim, consultative and participatory arrangements for water allocation will be required. Consultation is a key process in water allocation—along with data collection, analysis and promulgation, and negotiation—to find optimal sharing of benefits. The challenge over the next 20 years is to develop cost-effective arrangements for doing this and erect a functional framework of facilitating laws, treaties and regulations. Since the water allocation process is inherently political, effective representation is crucial. A major challenge for the coming decades is to develop strong and effective representative voices on behalf of those stakeholders now underrepresented, including small-scale farmers, women and the environment (World Bank, 2005).
Regulations	Governments can play a constructive role in influencing water allocation and affecting economic efficiency by establishing regulations, standards or requirements for upkeep of irrigation infrastructure. For an existing regulation to be economically efficient and achieve community support, the economic benefits of the regulation need to outweigh its costs, and the costs and benefits need to be shared fairly (Ward, 2010).
Data	In order to offer attractive investments for the private and public sector, good data are required to productively inform decisions on why, when, where and how to develop and sustain irrigation and its infrastructure. Collecting reliable data in developing countries is often challenging.

(*Continues*)

Table II. (Continued)

Sector	Challenges and constraints
Policies	A major challenge in national investment strategies will be how to arrive at a balance of polices that allows equitable development (for instance, policies favouring cheap imported pumps and motors) but constrain overuse (for instance, by limiting or withholding energy subsidies for abstraction).Investment will be required to more effectively monitor and regulate such private development (World Bank, 2005).

greatly affected by water scarcity, especially sub-Saharan Africa. It is specifically true in areas of economic water scarcity, where there is water available in nature, but limited accessibility due to financial and human capacity constraints. Here it will be fundamental to make sustainable investments in additional water supplies (i.e. through small-scale infrastructure) that help the poor and to set up institutions for sustainably managing the resource (Molden and de Fraiture, 2004).

Investment in building the capacity of people engaged in irrigation management is central. The tools and techniques for modern efficient irrigation practices are available but people need to be trained to use them properly. They need to focus on management. The FAO, very conscious of these needs, has, together with key partners, already taken some initiatives for raising this capacity through the promotion of reference centres and certification for management, and through better linkages with funding agencies.

In conclusion, investing in irrigation represents a key aspect in order to increase food production and alleviate poverty while reducing environmental costs and ensuring water conservation. However, it requires a long-term vision and commitment while several constraints have to be taken into consideration. Table II summarizes some of the main challenges that have to be taken into account in irrigation investment.

Innovations

Over the past many years, innovations in agricultural technology (precision agricultural innovations, data analytics and processing, platforms for the collection and distribution of complex data streams, and IT-driven extensions) have been on the rise. Through the use of these technologies along the entire agricultural value chain, the world can increase the productivity of its farming systems while simultaneously transforming agriculture into a source of environmental health. Crop sensing and modelling systems are able to remotely collect data such as humidity, barometric pressure, temperature, luminosity, wind speed, precipitation and soil moisture. These data, in turn, can predict the time and amount of irrigation.

Agriculture is the largest business sector which is highly driven by technologies and tools such as satellite imagery, aerial imagery, geographic information systems (GIS), global navigation satellite systems/global positioning systems (GNSS/GPS), automated sensors, high-tech machinery and high-resolution data. The ultimate purpose of all the technologies is about optimization, precision, and to efficiently produce high crop yields. It can be noted that present innovative technology or solutions in irrigation can be used to cater for needs and challenges in different subsectors. These innovative technologies or solutions in irrigation can be grouped into three main categories given below:

- *augmenting water supply*

* irrigation utilizing fog collectors; harvesting condensed water from humid air;
* cloud-seeding operation for water supply augmentation;
* solar and wind as sources of alternative energy in small-scale irrigation.

- *reducing losses*

* subsurface polyethylene (PE) pipeline irrigation;
* irrigation utilizing pressure-compensated subsurface drip lines;
* low-flow spray/?micro-sprinkler irrigation;
* irrigation canals using pre-cast methods;
* precision land levelling by laser-guided equipment for uniformity of flow of water into the soil;
* improving operation and maintenance of irrigation systems using farmland GIS;
* application of drone technology as a source of valuable information about when and where to apply precise quantities of water to the crop.

- *managing water demand*

* alternate wetting and drying schemes as water-saving technology;
* using a system of the rice intensification method for higher yield with minimum water demand.

REFERENCES

Amadei B. 2004. Engineering for the developing world. *The Bridge* **34**(3): 24–31.

Ayele K, Tedla S. 2006. Poverty reduction through irrigation and smallholder markets (PRISM). In *Best Practices and Technologies for Small Scale Agricultural Water Management in Ethiopia*, Proceedings of a MoARD/MoWR/USAID/IWMI Symposium, Addis Ababa, Ethiopia, 7–9 March.

Bakker M, Barker R, Meinzen-Dick R, Konradsen F. 1999. Multiple uses of water in irrigated areas: a case study from Sri Lanka. SWIM Paper 8. International Water Management Institute: Colombo, Sri Lanka.

Bhattarai M, Sakthivadivel R, Hussain I. 2002. Irrigation impacts on income inequality and poverty alleviation: policy issues and options for improved management of irrigation systems. Working Paper 39. International Water Management Institute: Colombo, Sri Lanka; 37 pp.

Brinegar H, Ward FA. 2009. Basin impacts of irrigation water conservation policy. *Ecological Economics* **69**: 414–426.

Bruns BR, Meinzen-Dick R. 2000. *Negotiating Water Rights*. Intermediate Technology Press: London, UK.

Chambers R. 1988. *Managing Canal Irrigation: Practical Analysis from South Asia*. Oxford & IBH Publishing Co. Pvt. Ltd: New Delhi, India; 281.

Food and Agriculture Organization of the United Nations (FAO). 2007. Modernizing irrigation management—the MASSCOTE approach: Mapping System and Services for Canal Operation Techniques, by D. Renault, T. Facon and R. Wahaj. FAO Irrigation and Drainage Paper No. 63. Rome.

Food and Agriculture Organization of the United Nations (FAO). 2013a. *Climate-smart Agriculture Sourcebook*. Rome, Italy; p. ix.

Food and Agriculture Organization of the United Nations (FAO). 2013b. Multiple uses of water services in large irrigation systems: Auditing and planning modernization—the MASSMUS Approach, by D. Renault, R. Wahaj and S. Smits. FAO Irrigation and Drainage Paper No. 67. Rome.

Food and Agriculture Organization of the United Nations (FAO) and World Water Council (WWC). 2015. Towards a water and food security future. Critical perspectives for policy makers. Rome, Italy and Marseille, France.

Food and Agriculture Organization of the United Nations (FAO). 2016. AQUASTAT website. Website accessed on 2016/05/10.

Global Water Partnership (GWP). 2012. *Groundwater Resources and Irrigated Agriculture—Making a Beneficial Relation More Sustainable*. www.gwptoolbox.org. 20.

Herrera PA, Van Huylenbroeck G, Espinel RL. 2006. Asymmetric information on the provision of irrigation through a public infrastructure: the case of the Peninsula of Santa Elena, Ecuador. *Water Resources Management* **20**: 431–447.

High Level Panel of Experts on Food Security and Nutrition (HLPE). 2015. *Water for Food Security and Nutrition*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome, Italy; 129 pp.

Hussain I, Hanjra MA. 2004. Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and Drainage* **53**: 1–15.

International Commission on Irrigation and Drainage (ICID). 2014. *Working Group on the Role of Irrigation on Poverty Alleviation and Livelihoods*. 22nd ICID Congress and 65th IEC, Gwangju, Republic of Korea, 14–20 September.

International Water Management Institute (IWMI). 2007. *Water for Food, Water for Life*, Molden D (ed.). Earthscan: London and International Water Management Institute: Colombo, Sri Lanka; Part 4, Chs 8–16.

Molden, D, de Fraiture C. 2004. Investing in water for food. Ecosystem and livelihood. Paper presented at the conference in Stockholm 2004 Blue Paper.

United Nations Department of Economic and Social Affairs (UNDESA). 2014. *Water and Food Security*. Available online: http://www.un.org/waterforlifedecade/food_security.shtml.Website accessed on 2016/05/10.

Ward FA. 2010. Financing irrigation water management and infrastructure: a review. Article in *International Journal of Water Resources Development* September; New Mexico State University, USA; **26**: 321–349.

World Bank. 2005. *Agriculture Investment Sourcebook*: Module 9: Investments in Land Administration, Policy and Markets. In *Agricultural Water*. The International Bank for Reconstruction and Development/The World Bank: Washington, DC, USA.