

# Water for Food

## Innovative water management technologies for food security and poverty alleviation



UNCTAD CURRENT STUDIES ON SCIENCE, TECHNOLOGY AND INNOVATION.

**N°4**



UNITED NATIONS

# Water for Food

## Innovative water management technologies for food security and poverty alleviation



UNCTAD CURRENT STUDIES ON SCIENCE, TECHNOLOGY AND INNOVATION.

**N°4**



UNITED NATIONS  
New York and Geneva, 2011

## NOTE

The United Nations Conference on Trade and Development (UNCTAD) serves as the lead entity within the United Nations Secretariat for matters related to science and technology as part of its work on the integrated treatment of trade and development, investment and finance. The current work programme of UNCTAD is based on the mandates set at UNCTAD XII, held in 2008 in Accra, Ghana, as well as on the decisions by the United Nations Commission on Science and Technology for Development (CSTD), which is served by the UNCTAD secretariat. UNCTAD's work programme is built on its three pillars of research analysis, consensus-building and technical cooperation, and is carried out through intergovernmental deliberations, research and analysis, technical assistance activities, seminars, workshops and conferences.

This series of publications seeks to contribute to exploring current issues in science, technology and innovation, with particular emphasis on their impact on developing countries.

The term "country" as used in this study also refers, as appropriate, to territories or areas; the designations employed and the presentation of the material do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delineation of its frontiers or boundaries. In addition, the designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgement about the stage of development reached by a particular country or area in the development process. Mention of any firm, organization or policies does not imply endorsement by the United Nations.

The material contained in this publication may be freely quoted with appropriate acknowledgement.

---

## ACKNOWLEDGEMENTS

This study was prepared by Melvyn Kay (consultant to UNCTAD) under the direction of Dong Wu. Juana Paola Bustamante and Jenny Lieu contributed to research. Anne Miroux and Mongi Hamdi provided overall guidance.

Comments were received from the following UNCTAD staff members: Ulrich Hoffmann, Oliver Johnson and Jason Munyan.

UNCTAD also wishes to acknowledge comments and suggestions provided by David Molden and Barbara Van Koppen (International Water Management Institute), Rudolph Cleveringa (International Fund for Agricultural Development), Timothy Karpouzoglou (SPRU, University of Sussex) Shirley Malcom and Sophia Huyer (Gender Advisory Board, UN Commission on Science and Technology for Development), Vijaya Kumar (Chairman, Industrial Technology Institute, Sri Lanka), as well as from members of the Commission on Science and Technology for Development.

Laurence Duchemin formatted the manuscript. Nadege Hadjemian designed the cover. Michael Gibson edited the report.

---

## ABBREVIATIONS

AgWA	Agricultural Water for Africa
AMCOW	African Minister's Council on Water
AWM	Agricultural Water Management
BRIC	Brazil, Russia, India and China
CAADP	Comprehensive Africa Agriculture Development Programme
CP-MUS	Challenge Program-Multiple-Use Water Systems
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
IDE	International Development Enterprises
IFAD	International Fund for Agricultural Development
LDC	Least Developed Country
MDG	Millennium Development Goals
NEPAD	New Partnership for Africa's Development
SIMI	Nepal Smallholder Market Initiative
IWMI	International Water Management Institute
OECD	Organisation for Economic Co-operation and Development
PPP	Public Private Partnership
SSA	sub-Saharan Africa
WHO	World Health Organisation

---

# CONTENTS

Acknowledgements .....	iii
<b>1. AGRICULTURE AND WATER.....</b>	<b>1</b>
<b>2. A 'PERFECT STORM'? .....</b>	<b>1</b>
2.1 Climate change – another dark cloud.....	2
2.2 Some 'white' clouds .....	3
2.3 Focusing on water technologies .....	3
<b>3. THERE IS ENOUGH WATER.....</b>	<b>3</b>
<b>4. THE RAINFED-IRRIGATION NEXUS .....</b>	<b>4</b>
4.1 What about drainage?.....	4
4.2 In Asia.....	5
4.3 In Africa .....	6
4.4 In Latin America and the Caribbean .....	7
<b>5. WHAT IS TECHNOLOGY'S ROLE? .....</b>	<b>8</b>
5.1 Water storage .....	10
5.2 Re-thinking canal irrigation.....	10
5.3 Mico- irrigation technologies.....	11
5.4 Water lifting.....	12
5.5 ICT in water management.....	15
5.6 Common and unconventional water sources .....	15
5.7 Improved rain-fed agriculture.....	17
5.8 Conservation agriculture .....	17
<b>6. WHAT NEEDS TO BE DONE? .....</b>	<b>17</b>
6.1 Focus more on women .....	18
6.2 Focus on existing technologies .....	20
6.3 More research for development and better dissemination.....	20
6.4 Smarter water management.....	21
6.5 Build new institutions.....	21
6.6 Develop AWM capacity .....	22
6.7 Support Public-Private-Partnership.....	22
6.8 Encourage the private sector .....	22
6.9 Focus more on youth .....	23
6.10 Increase water-food trade .....	23
6.11 Strategy in Asia .....	23

6.12 Strategy in Africa .....	23
6.13 Strategy in Latin America and the Caribbean .....	24
<b>7. WHERE, FOR WHOM, AND HOW?.....</b>	<b>24</b>
<b>8. CONCLUSION .....</b>	<b>25</b>
<b>9. REFERENCES .....</b>	<b>27</b>

---

## WATER FOR FOOD – INNOVATIVE WATER MANAGEMENT TECHNOLOGIES FOR FOOD SECURITY AND POVERTY ALLEVIATION

**Modern irrigation is one of the success stories of the 20th century. As the world's population doubled, irrigated farming expanded from 40 million ha to almost 300 million ha today – a seven-fold increase. This revolution in water technology increased food production through improved crop yields and enabled farmers to grow additional crops each year. China, India, Indonesia, and Pakistan together account for almost half the world's irrigated area and they rely on irrigation for more than half their domestic food production.**

**But the world's population continues to grow, mostly in the LDCs, and so do concerns about food security and particularly the availability of water to grow crops. Global agricultural food production already accounts for 70 per cent of all water withdrawn from rivers and aquifers. Climate change will only make matters worse.**

**Can agricultural water management (AWM) technologies provide innovative solutions that can help to meet this challenge of feeding a growing, mostly disadvantaged, population by producing more food but with fewer resources? This paper reviews the water-food-poverty nexus and examines the role that AWM technologies may play in achieving world food and water security.**

### 1. Agriculture and water

Agriculture is central to food security and economic growth in developing countries and provides the main source of livelihood for three out of four of the world's poor (Wheeler and Kay, 2010). But food production requires substantial amounts of water. Globally, agriculture accounts for 70 percent of all water withdrawn from rivers and aquifers. Several regions are already facing acute physical water scarcity – North Africa, South Asia, and the drier regions of sub-Saharan Africa (SSA). Water scarcity is one of the most pressing issues facing humanity today. More than 1.4 billion people live in water stressed rivers basins and by 2025 the number is expected to reach 3.5 billion. Moreover, today more than 20 percent of the world's rivers run dry before reaching the sea (World Resources Institute, 2003).

This situation is set to deteriorate. Global food demand is expected to increase by as much as 70 percent by 2050 (FAO, 2006a) as the world's population rises from 6.5 billion to 9 billion and diets change as a result of socio-economic improvements, particularly in OECD and BRIC countries. About 1.4 billion people live in extreme poverty (defined by the World Bank living on less than \$1.25 a day). Most are living in LDCs in Asia and Africa and to a lesser extent in Latin America and the Caribbean (Figure 1). Even though there is a shift towards urbanisation, poverty is still largely a rural problem (approximately 1 billion) and this is likely to remain so for the foreseeable future (IFAD, 2011). Not only is poverty highly regionalized and rural, it is also disproportionately female (Rauch, 2009) as men are drawn to the cities to seek alternative incomes. In developing countries, women provide around 43 percent of the labour force. In sub-Saharan Africa, 62.2 percent of the region's economically active women are engaged in the agricultural sector (FAO, 2011).

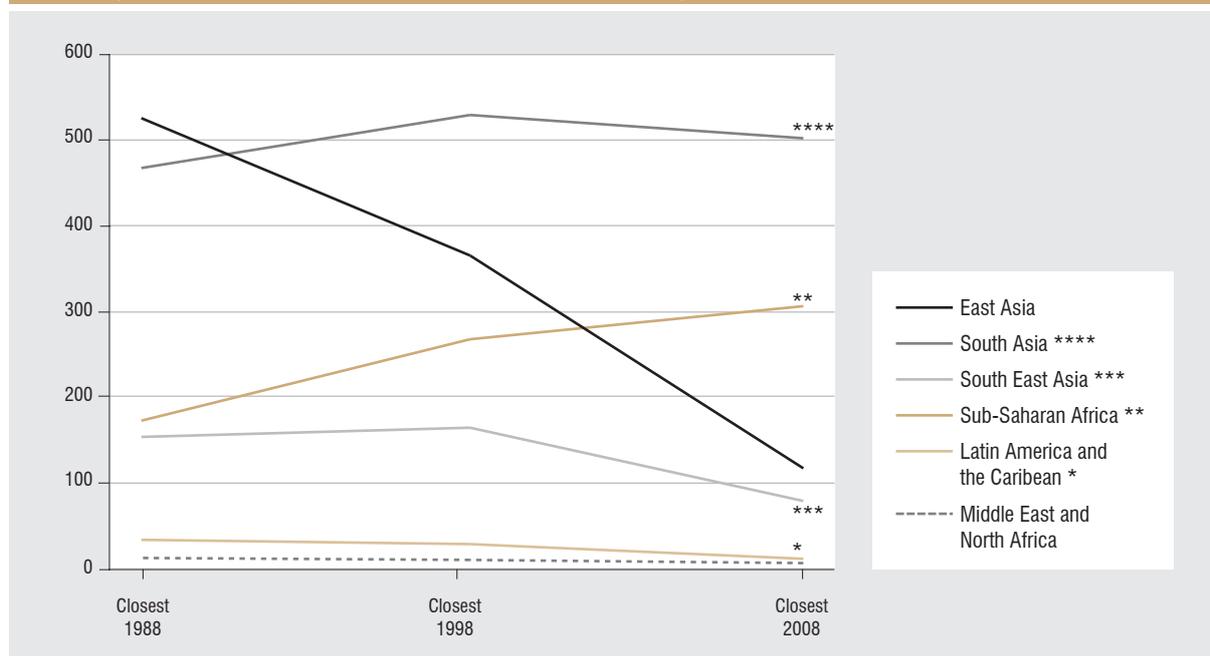
Food demand in LDCs is expected to double as the population in the developing world reaches 7.5 billion by 2050 – 2.2 billion in south Asia and 5 billion in SSA. Most LDC governments look to their rural communities to produce more agricultural products but those same communities are impoverished, their productivity is low, as is their resource use efficiency.

The burden of the poor is made worse by the changing nature of rural life – the new 'rurality' (Rauch, 2009). Globalisation is transforming the marketplace; new patterns of poverty are emerging as livelihoods adjust; reforms in governance and rural service systems are changing the nature of institutions. All these issues create uncertainty and risk and are likely to have a disproportionate impact on the rural poor and their ability to access and make good use of limited water resources.

### 2. A 'perfect storm'?

Water resources are already under stress in many parts of the world yet the demand for water will substantially increase in order to meet the additional requirements for food and energy crops. Competition for water will inevitably intensify between the different water using sectors – municipalities, industry, agriculture and the environment. There are increasing pressures to divert land away from food production towards energy crops. Energy consumption is expected to rise significantly as

**Figure 1. Rural people living in extreme poverty (IFAD, 2011).**  
(Millions of rural people living on less than US\$1.25/day)



Source: IFAD, 2011

more fertilizers are needed to grow additional crops. The dilemma is that land and water resources are not increasing, rather there are concerns that available water resources will decrease in some critical regions as a result of climatic changes and the available land area for agriculture will continue to decline because of land degradation and urbanisation.

The range of issues has created a 'perfect storm' with 'dark clouds' converging towards 2030 and beyond to produce problems far greater than the sum of the parts. As most of the population increase will be among those already disadvantaged in the developing world, there may be increased competition for food, water, and energy; rises in food prices; and increases in the number of people going hungry (Bennington, 2009).

## 2.1 Climate change – another dark cloud

Climate change is yet another 'dark cloud' on the horizon that will impact water resources which in turn will impact agriculture and hence food production (Bates *et al*, 2008). Globally, agriculture contributes about 18 per cent of greenhouse gas (GHG) emissions, largely through livestock production, land use changes, paddy rice production, and the manufacture and use of agro-chemicals (Smith *et al*, 2007; UNCTAD, 2010).

Rising global temperatures will result in drier dry seasons and wetter rainy seasons, greater uncertainty, and increase the risk of more extreme and frequent floods and droughts. The IPCC projected an increase in annual mean rainfall in high latitudes and South East Asia and decreased rainfall in Central Asia, the southern Mediterranean, and sub-Saharan Africa. Such changes will impact people's livelihoods and ecosystems, particularly in semi-arid and arid areas where the poorest live.

Decreasing rainfall, particularly in areas that are already water-short, will impact both surface and groundwater supplies. Melting glaciers will initially increase but then strongly decrease dry-season water supplies. This will affect the design of new water infrastructure. Design is normally based on historical weather patterns but this will no longer be helpful in predicting what may happen in the future.

The poorest farmers are at greatest risk from the impacts of climate change (Parry *et al*, 2005). Increasing food, feed, and biofuel production will in turn increase GHGs and this will significantly impact both the availability of food and food security (Schmidhuber and Tubiello, 2007). Climate change will counter the drive for increased food production in many LDCs and hinder progress towards meeting

MDG 1 – which aims to reduce by half the portion of people suffering from hunger by 2015). Additionally, climate change will increase inequality because most vulnerable farmers live in places with marginal crop production and limited access to agricultural knowledge and technology.

## 2.2 Some ‘white’ clouds

The prognosis sounds rather gloomy and there are skeptics who disagree with these predictions. However, the arguments have more to do with the timing of events rather than the nature of the serious crisis the world faces towards the middle of the 21<sup>st</sup> century. But there are some white clouds as well as dark ones. In the second half of the 20<sup>th</sup> century world food production more than doubled in response to a doubling of the population. Agricultural productivity has risen steadily over the past 40 years and irrigated agriculture is one of the success stories of the 20<sup>th</sup> century. The large irrigation schemes in India, China, Pakistan, and Indonesia have fed millions who would have otherwise starved. The ‘green’ revolution, in the 1960s and 1970s, essentially based on rice irrigation, lifted Asia out of an imminent hunger crisis although the price was heavy in terms of water and energy.

In the 1990s the importance of water for ecosystems and their resilience became well recognised as did the need to strike a balance between water for food, people, industry, and for the environment. There was a proposed a ‘green-green’ revolution (Conway, 1997) founded on the principles of environmental sustainability. Another concept of a third ‘green dimension’ (Falkenmark, 2006) was introduced which focuses on upgrading rainfed agriculture. Indeed, many developing countries still have a large, untapped endowment of rainfall that can be harnessed using conservation farming practices and supplementary irrigation.

## 2.3 Focusing on water technologies

What does this mean for global food security? The UK House of Commons report (HOC, 2010) put it thus: “the world must produce 50 percent more food – ‘safe food’<sup>1</sup>, on less land, with less freshwater, using less energy, fertilizers, and pesticides – by 2030 whilst at the same time bringing down sharply the level of GHG emissions emitted globally”. It is a daunting challenge but one that can and must be met.

This paper focuses on agricultural uses of water and

the role that innovation and technologies can play in meeting this challenge whilst recognizing that agricultural water technologies are only one piece, but a crucial one, in the complex jigsaw of global food security.

## 3. There is enough water

Crops consume large amounts of water, so is there enough to meet future demand or will supplies run out? The simplistic answer is yes – but only if we make better use of what is available (CA, 2007).

Of the 110,000 km<sup>3</sup> of rain that falls annually on the earth’s surface, 36 percent ends up in the sea; forestry, grazing lands, and fisheries, and biodiversity consume 57 percent; towns, cities, and industry use just 0.1 percent (11 km<sup>3</sup>); while agriculture consumes 7 percent (7,130 km<sup>3</sup>). Some 22 percent of agriculture’s water consumption (1,570 km<sup>3</sup>) is ‘blue water’ – water withdrawn from rivers, streams, and groundwater for irrigation purposes. Most of agriculture’s water consumption (5,560 km<sup>3</sup>) is ‘green water’ – water available to crops from rainfall stored in the soil root zone (CA, 2007).

Predicting future water demand is fraught with difficulties. Forecasts made less than 10 years ago have already been proved inaccurate because no one accurately predicted the rise in energy prices nor the world recession and the impact these factors would have on food prices. The impacts of climate change are now only beginning to unfold as are the stresses of population growth and water scarcity. But the simple answer to the question is – yes we have enough water but only if we act now to improve how water is used, particularly in agriculture which is the main consumer (CA, 2007). What is certain is that the future of food security and water security are inextricably connected.

If water usage continues at the present rate, global water consumption will almost double by 2050. However, a more optimistic assessment suggests it may rise from 7,130 km<sup>3</sup> to 8,515 km<sup>3</sup>/yr by 2050 (CA, 2007). This is not only based on predictions of population increase but also on improving socio-economic conditions and nutrition – both of which demand more water. The greatest change over the past 30 years has been the shift away from starch-based diets to meat, eggs, and dairy products to a point where livestock products account for about 45 percent of the global water embedded in food products. Growth has been most rapid in East and

Southeast Asia, particularly China, and in Brazil. In 2009, China was the top meat producer making up 27.4 percent of the overall meat production while India produced 15.3 percent of the world's milk and milk products (FAO, 2010d). Predictions are based on anticipated changes in cropping and diets, likely improvements in water productivity in rainfed and irrigated agriculture, increases in cropped area, the expansion of agricultural trade from water-rich to water-poor countries, and technology transfer through the efforts of national and international research centres<sup>2</sup>.

#### 4. The rainfed-irrigation nexus

Agriculture is a mix of rainfed and irrigation farming. Globally rainfed farming is the world's most common farming system practised on 80 percent of cultivated land and accounting for 60 percent of the world's food production. In areas of high and reliable rainfall such as in northern Europe, crop yields are good and production is reliable. But in areas of low, erratic, and unreliable rainfall, such as the drier regions of Africa where many of the poor and disadvantaged live, crop yields are low and uncertain – grain yields average only 1 ton/ha and water consumption is high because of the high evapotranspiration rates between 2,000-3,000 m<sup>3</sup>/ton of crop. This is roughly twice the global average of 1,000-1,500 m<sup>3</sup>/ton of crop. The ability of most smallholder farmers to make better use of rainwater is limited. The fraction of rainfall used for crop transpiration is only 15-30 percent (Wallace, 2000) and sometimes it is as low as 5 percent (Rockstrom and Falkenmark, 2000).

Globally, irrigation is only practised on about 300 million ha (in 2010) – 20 percent of the cultivated land area (FAO, 2010a). But its contribution is substantial – more than 40 percent of the world's food production. About 80 percent of the irrigated area is in Africa, Asia, Latin America, and the Caribbean. There is still room for expansion, particularly in sub-Saharan Africa in places where there is sufficient water available.

Irrigated agriculture offers great potential for economic growth and poverty reduction. In the right circumstances, irrigation can reduce the risks associated with the unpredictable nature of rainfed agriculture in dry regions and increase cropping intensities in humid and tropical zones by 'extending' the wet season and introducing effective means of water control. It can provide a defence against droughts, which are

predicted to occur more frequently as the climate changes. Irrigation can increase crop diversity, produce higher yields, enhance employment and lower food prices (IFAD, 2008). Indirectly it can stimulate input and output markets, stabilize output and economic activities thus providing substantial benefits across economic sectors.

But, like rainfed farming, there are concerns about water wastage. The global average for plant transpiration is around 30 percent. The remaining portion is lost through surface runoff, drainage, and unproductive evaporation. In sub-Saharan Africa around 15-30 percent of rainfall is actually transpired by the crop. Crops in arid lands draw in only approximately 10 percent of the rainfall and degraded land (with output less than 1t/ha) transpire only 5 percent of the rainfall. This 'inefficiency' is an overriding concern among those in irrigation (IWMI, 2009).

Although rainfed and irrigation farming are often considered to be separate and distinct ways of growing crops, in practice they overlap – natural rainfall contributes to irrigation farming and irrigation is used to supplement inadequate rainfall. Agriculture exploits both blue and green water often at the same time, to meet crop water requirements. This approach to thinking about water is breaking down the traditional divisions between blue and green water and is shifting water resources planning from dealing with runoff (blue water) to a process that values both blue and green water. This is the essence of 'agricultural water management' (AWM) (Falkenmark, 2006).

##### 4.1 What about drainage?

Irrigation and rainfall are usually the main issues in agricultural water management and so they attract most attention. But in many situations drainage, the reverse of applying water to crops, also plays a key part. Excess water is drained from the land in order to provide the right moisture conditions for crops to grow.

In arid and semi-arid areas, where irrigation is indispensable for agriculture, drainage can prevent water logging and the build up of salts in the soil profile which comes from poor quality irrigation water. Salinization affected about 20-30 million ha of the world's 300 million ha (7-10 percent) of irrigated land in 2002, while in 2008, around 20 percent of the irrigated land was affected by salt. About 10-20 per cent of irrigated land is already equipped with drainage, but

40-60 per cent is in need of drainage but there are no facilities installed. The problem is most acute in South and Central Asia and the Near East where arid climate prevails and irrigation is widely practiced (FAO, 2002; FAO, 2008).

Drainage is also important in the humid and sub-humid tropics, such as East and South East Asia and parts of West and Central Africa, where the main objective is to remove excess water from high or intense rainfall. Lack of drainage and inadequate protection from flooding are major obstacles to agricultural development and constrains farmers from intensifying and diversifying their cropping.

In temperate zones, in Europe and North America for example, drainage also helps to maximize production by improving soil moisture and the timeliness of farm mechanisation operations.

Drainage technologies are well known and established across the world but drainage is one of the neglected areas of agricultural water management that deserves more recognition.

#### 4.2 In Asia<sup>3</sup>

Asia is one of the main challenge areas where water scarcity and AWM development are directly linked to extreme poverty and hunger (Figure 1). About 700 million people subsist in extreme poverty. They rely heavily on irrigation farming which accounts for 70 percent of the world's irrigated area and almost one third of the region's cropland (Mukherji *et al*, 2009). Agricultural output has been largely technology driven. Many large irrigation schemes were built in the 1960s and 1970s to supply water to smallholders and this provided the engine to drive Asia's green revolution. This enabled the region to become food self-sufficient by providing timely and reliable water supplies, which in turn led to greater cropping intensities, high yielding rice varieties, and the use of fertilizers that pushed up productivity.

However, inappropriate fertilizer and pesticide usage has caused ecological damage and water pollution from fertilizer runoff. A general lack of water management in Asia has also led to salinization and waterlogging. Salinization alone affects over 40 percent of Asia's irrigated land in dry areas. (IFAD, 2009c). In countries such as China and India, the increased use of surface water for irrigation has raised the water table causing water logging; on the other hand, increased use of groundwater irrigation over

the past decades has caused water tables to drop on average by  $\leq 1$  metre per annum. In both cases stream flows have decreased (Scanlon *et al*. 2006). Additionally, water quality has also become a serious issue in China where 7.4 percent of the irrigated land (equivalent to 4.05 million hectares) are supplied with polluted water. According to China's Ministry of Environmental Protection, in 2008, 46.2 percent of the 26 lakes and reservoirs monitored for its environmental state were experiencing eutrophication, or oxygen depletion (quoted. in AWP, 2010).

Water pollution and overuse exacerbates poverty, which is particularly a problem in South Asia. By 2050 there will be an additional 1.5 billion in Asia, half of whom will still live in rural areas in spite of the tendency towards urbanization. Diets too are changing rapidly among the wealthier population as they turn to meat and dairy foods which require much more water than vegetables. In East and Southeast Asia meat consumption has risen by almost 30 percent in the past 10 years (FAO, 2009) – a trend that will appear to continue.

Land and water resources across the region are limited and, although there is rainfed farming, irrigation farming is expected to deliver most of the additional food, mainly from existing irrigation systems through raising yields and the productivity of land and water resources. Some food supplies are expected to come from international trade. But the existing schemes that once dominated agricultural production, are now in decline because of poor maintenance, salinity, and water logging. Further investment in irrigation was discouraged because of lower food prices and poor rates of return. The result is that many of the large scale, centrally managed irrigation systems are in need of modernization to cope with modern farming practices and the changes in food demands. Efforts to rehabilitate them are mixed.

Millions of smallholders in South and Southeast Asia are now taking matters into their own hands and investing in locally adapted technologies such as small storage ponds, PVC (polyvinyl chloride) piping, and pumping equipment in order to access groundwater and gain greater control over their water supplies (Mukherji *et al*, 2009). This puts the reliability, timeliness, and adequacy of irrigation in the farmer's control. This new 'water-scavenging' economy, as it is known, is now highly visible in South Asia and the North China Plains. Groundwater abstraction is encouraged by a booming low-cost Chinese pump industry. China has

pared down the weight and cost of small pumps and currently exports some 4 million pumps annually. In India more than 60 percent of the nation's irrigation now comprises smallholders pumping groundwater, known as 'atomistic irrigation'. But the success of this 'smallholder' approach to farming is now beginning to create large scale problems as the many thousands of mostly unregulated withdrawals are over-exploiting groundwater and water tables are falling in some places by as much as 3m/year (Mukherji, 2009). This calls into question the long-term sustainability of this informal irrigation economy unless steps are taken to increase groundwater recharge. As Postel (2010) states 'we are meeting some of today's food needs with tomorrow's water'. Groundwater across northern India is estimated to deplete annually by 54 cubic kilometers. The high energy consumption of lift-based irrigation when compared to gravity systems also makes long-term sustainability an issue (Postel, 2010).

### 4.3 In Africa

Africa is another region where water and poverty are linked together (Figure 1). Africa, particularly sub-Saharan Africa (SSA) has little irrigation and agriculture is dominated by rainfed farming which is largely subsistence based and concentrated on low-value food crops (AfDB *et al*, 2007). Over 330 million people, some 45 percent of the population, live in extreme poverty. Agricultural productivity is the lowest in the world and output has not kept pace with population increase. Since 1980, over 80 percent of output growth has come from expanding the cropped area. This is in stark contrast to other regions where increases in cropped area have been less than 20 percent with changes in technology and innovation driving additional productivity. This is clearly not the case in SSA (Svendsen, 2009).

Although rainfed farming predominates, rainfall in many of the drier regions of Africa is erratic and unreliable, rainy seasons are short and there are often long gaps between rainfall events. 'Just one more good storm' is a constant lament among African farmers who must make a living in some of the driest regions of the world (NRSP, 2000). But floods as well as droughts are hazardous. Over the past century, floods have caused more than 40 percent of all declared disasters in the United Republic of Tanzania while droughts have caused only 30 percent - often in the same place and in the same season (NRSP,

2002). Climate change predictions suggest that this may worsen as the extremes of droughts and floods increase. The fragile nature of agricultural production in SSA and its dependency on climate conditions is well illustrated in Box 1.

Rainfed farming is where the greatest potential exists for improving output and productivity. Even modest low-cost technological improvements and modest increases in yield could have significant impacts on production and poverty reduction.

Irrigation in North Africa is concentrated in the north along the Mediterranean and, except for Egypt and The Sudan which rely on the River Nile, irrigation is mainly from groundwater. But renewable groundwater resources are severely over-exploited and fossil water reserves are also being mined. This is driven by governments providing substantial subsidies for irrigation equipment, pumps, and energy in order to achieve self-sufficiency in staple foods. However, this situation is just not sustainable (World Bank, 2007).

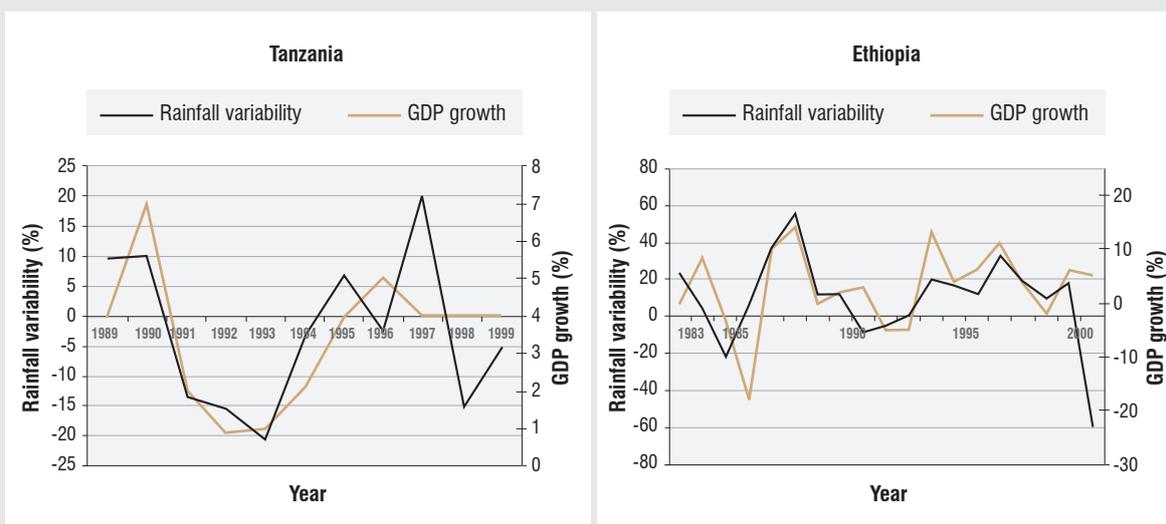
In SSA the picture is quite different. The share of the cultivated area equipped for irrigation is only a third of the world average and just one-sixth of the value for Asia. Past experiences of investment in irrigation are not good. International donors have shown little interest over the past 30 years following disappointing investments in irrigation in the 1960s and 70s. National governments too have struggled to keep water for food on the national water agenda in spite of the fact that in most African countries food production is the largest consumer of water.

The reasons for this are numerous and complex. They range from relatively low population densities to the lack of market access and incentives for agricultural intensification, low quality soils, unfavourable topography, and inadequate policy environments that do not recognize the predominance of women in agriculture. Together with development costs, which are considerably higher than in Asia, these conditions seriously limit the economic feasibility of irrigation development projects (IFAD, 2008).

Yet renewable water resources per capita are substantial and suggest there is a large untapped endowment of water that could be used for irrigated agriculture. In SSA only 7 million ha (4 percent of cultivated land) is equipped for irrigation. This area almost doubles when North Africa is included – Egypt accounts for 20 percent of all irrigation in Africa. Even within this modest total it is estimated that about 20 percent of

**Box 1: The link between GDP and rainfall**

Such is the fragility of some developing countries that drought impacts directly and severely on economic growth. The figures below illustrate the pattern of rainfall and GDP growth from 1989 to 1999 in the United Republic of Tanzania and from 1983 to 2000 in Ethiopia. In Ethiopia 75 per cent of the population depend on small scale and rainfed cropping. During the famine in the early 1990s, rainfall was well below average and economic growth plunged hitting agriculture the hardest. A similar situation is observed in the United Republic of Tanzania and is common to other sub-Saharan countries.



Source: World Bank, 2006a; 2006b cited in Van Aalst, M. et al., 2007

the irrigated area is not operational (Svendsen *et al*, 2009). These figures represent the more formal irrigation schemes and do not include the many thousands of hectares of informal private, smallholder irrigation across the region in valley bottoms, along flood plains, and in peri-urban areas using wastewater, which do not appear in official government statistics. For instance, in Nigeria, several hundred thousand hectares of the fadamas wetland valleys are estimated to be informally irrigated (IWMI, 2007).

Nevertheless, Africa produces 38 percent of its crops (by value) from only 7 percent of cultivated land on which water is managed suggesting that additional investment in irrigation would pay dividends. The disproportionate contribution to agricultural production of Africa's small irrigated area suggests that returns on additional investment in irrigation would be high, both in terms of greater food security for the continent and greater production of export-quality agricultural goods (Svendsen *et al*, 2009).

The different agro-ecological zones across the continent will require different approaches and there

is a need to move from a 'top-down' to a 'bottom-up' livelihoods-based paradigm which recognises the role that women play in agriculture. Should a "green revolution" happen in SSA, it is likely to differ considerably from that in Asia, given the significant differences in resource endowments, demographics, lack of appropriate technologies, public perspectives regarding government support for intensive agriculture, and the completely different economic context at both local and international level (IFAD, 2008).

#### 4.4 In Latin America and the Caribbean

The third region in which poverty persists, though not to the same extent as in Africa and Asia, is Latin America and the Caribbean (Figure 1). The region's population has grown rapidly from 244 million in 1966 to 515 million in 2000 and is expected to reach 705 million by 2030. About 11 million live extreme poverty, but in contrast to Asia and Africa, most live in the urbanised regions (IFAD, 2011).

Most Latin-American countries have substantial endowments of water. The region has over 30 percent of

the available global water supply and only 8.6 percent of the world's population. But there are large disparities between and within countries. More than half the renewable water supply is concentrated in one river – the Amazon. The Caribbean islands in particular suffer from water shortages. The distribution of people is also uneven; some 60 percent of the population is concentrated on 20 percent of the land area that has only 5 percent of the renewable water resources.

Agriculture is the main consumer of fresh water even though the irrigated area is modest in comparison to Asia and SSA. Latin America relies extensively on rainfed farming though there is approximately 13.5 million ha of irrigated agriculture (in 2009) – about 9 percent of the estimated world total. Mexico has by far the largest irrigated area with over 6.5 million ha, Brazil is next with 3.2 million ha, followed by Chile, Argentina, and Bolivia. About 0.5 million ha in Brazil is in the semi-arid North East region – an area with the lowest social and economic indicators (Oliviera et al, 2009). Unlike Asia and Africa, Latin America has a strong tradition of private investment in irrigation with governments acting as regulator and enablers of investment. In recent years investment in water for agriculture has been in decline. The costs of construction have been increasing, government support for large scale irrigation investments has been limited, and there are concerns about the negative social and environmental impacts of irrigation. Existing schemes are generally not well managed.

Population growth and rapid urbanisation are putting considerable pressure on water available for irrigation (Ringler, 2000). As 70-80 per cent of the population lives in urban centres there is pressure to transfer water from agriculture to supply the growing urban populations.

In many areas water scarcity is made worse by severe water quality problems resulting from poorly treated domestic and industrial sewage and mining wastes. In Mexico only 40 percent of wastewater collected in the country's 1 833 plants were treated in 2008 (National Water Commission of Mexico, 2010). Continued population growth and increasing urbanisation will only make matters worse. Runoff from agricultural land containing agricultural chemicals is also a major pollution issue in some countries – Chile, Colombia, Costa Rica, El Salvador – where fertilizer use has increased rapidly over the past 30 years to levels similar to those in the OECD countries. Overall, in Latin America and the Caribbean, about 20 percent of all

wastewater is treated while the existing infrastructure can theoretically treat around 35 percent of the wastewater (Mejia, 2010).

Lack of effective drainage affects large areas of land and in many cases this is compounded by salinization and water logging. In Argentina, Cuba, Mexico, Peru and Brazil, salinization from irrigation is becoming an increasingly pressing issue. Additionally, water logged valleys have covered around 1.2 million hectares in Brazil. However, not all areas in the region are in dire conditions. For instance, Mexico has the largest drainage infrastructure in the region with 2.8 million hectares of irrigated districts and 2.4 million hectares of supplemental irrigation<sup>4</sup> (Mejia, 2010).

Although the region would seem to have plentiful supplies of water overall, the drier regions are cause for concern and so investment in irrigation to address water logged areas and salinization must be an important part of the region's strategy for both water and food security, and poverty reduction.

## 5. What is technology's role?

What role has AWM technologies played in getting us to where we are now and equally important what options and opportunities does technology offer for the future? The innovative use of technology is not just a feature of water management; it is essential and often provides the catalyst for the broader aspects of agricultural development in LDCs. Decisions about technology are among the first to be made in the development process and it is important for all those involved in AWM to make the right choices.

The large public irrigation schemes depend on technology for major water storage, flow control and measurement, lifting water, and for data collection on which management decisions are based. Without these technologies irrigation water managers cannot begin to properly manage and distribute water. But the high costs of large schemes, concerns about their social and environmental sustainability, and the lack of benefits for the poorest farmers have slowed new developments in recent years.

In many LDCs attention has shifted away from engineering large irrigation schemes to a focus on smallholders who depend on agriculture for their livelihood. Smallholders make up about 80 percent of Africa's population. They manage rainfall and/or irrigate small farms and home gardens, often less than 1 ha in size and are the backbone of African

agriculture. A similar situation exists in the poorer regions of Asia. Smallholders usually have direct access to surface or groundwater and make their own decisions about how they will use water. They practice a mix of commercial and subsistence farming where the family provides the majority of the labour and the farm is the principal source of income. In such situations technology can greatly reduce the drudgery of lifting water as well as help solve water management problems by simplifying the process of watering crops in an adequate and timely manner. But the 'right' technology must be applied, enabling users to innovate and adapt the technology to their circumstances. Above all it must be simple to construct, reliable to use, easy to maintain, and consider gender specific needs. The focus on the small-scale has also substantially reduced development costs but there is the danger that low cost technology can become a euphemism for cheap and poor engineering. In SSA there are examples of so-called low-cost irrigation schemes in which canal embankments have not been properly engineered resulting in leaks and requiring substantial and costly maintenance.

Technology must also make effective and sustainable use of eco-system services. Whereas many services to society come from man-made infrastructure, these come from the 'green infrastructure' – healthy rivers and watersheds that filter out pollution, mitigate floods and droughts, recharge groundwater, and maintain fisheries. Technologies which maintain and enhance such services build resilience into our water delivery systems and water use.

What technology should be adopted? This is a key question but it is not the only aspect to consider. It must be posed in the context of where it is being

used (location), by whom (people), and how will it be introduced and implemented.

Generally, technologies fall into two main categories, those which make better use of available water: water saving options that help to increase water productivity (the benefit derived from each litre of water); and those which make more water available including water storage to cope with seasonality, increasingly variable and unpredictable rainfall, flooding, and drought. This is often referred to as the 'twin-track' approach, the emphasis depending on local circumstances. In many of the drier regions of the world for example, traditional blue water resources are already over-exploited and the costs of making more water available are becoming increasingly prohibitive. Decision-makers often respond to water needs by building larger versions of familiar technologies – larger dams, deeper wells, bigger pumps, or water transfer from one catchment to another. Extending existing technologies alone, however, does not address unsustainable water use; rather appropriate technological solutions must be combined with improved water management and efficient water use. Furthermore, in dry areas water management can go hand in hand with opportunities to capture more green water locally and so make more available as well.

Although new water technologies are available, existing technologies have a higher potential for immediate application. Some of the more promising technologies are listed below. Whichever technology is used, success will be determined more by the capacity of smallholders to take risks, innovate and adopt them in situations where services are erratic, costs are high, and markets are unpredictable rather than what is potentially and technologically possible.

#### Box 2: Some principles for intervening in smallholder irrigation

New inventions that match the performance criteria of affordability, suitability and high returns are unlikely in smallholder irrigation and so it is likely that the main focus will be on adapting and optimising existing technologies.

Adapting existing irrigation technologies and affordability are the critical issues for developing irrigation systems for smallholders.

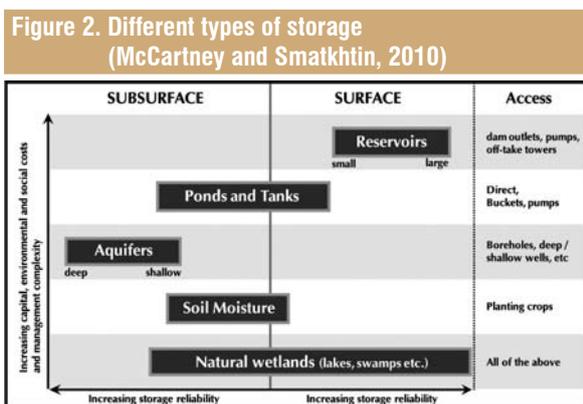
The first principle of affordability is that the initial purchase price of a product must be low enough to be affordable within the constraints of current disposable income.

Only in the past decade have there been attempts to fill the gap between buckets and 5kW motorised pumps and to devise water lifting devices and distribution systems that are suited to plots of less than 0.1ha. Such innovations have begun to create new markets that can open up opportunities for smallholders.

*Source: Unpublished World Bank handbook on smallholder irrigation, 2002*

## 5.1 Water storage

Water storage has perhaps the greatest potential to deliver the improvements in water management. Storage is a (very) old technology and is one that has been exploited throughout history. Water storage is often associated with dams and environmental and social problems. Over 45,000 large dams have been built for storage across the world and some 40 percent are used for irrigation purposes; but dams are just one means of storage. The IWMI describes storage as a continuum involving both surface and subsurface storage. Surface storage includes natural wetlands and reservoirs and subsurface storage consists of groundwater aquifers and soil water storage that can be accessed by plant root, tanks, and ponds (Figure 2) (McCartney, 2010).



Source: McCartney and Smatkhtin, 2010

Storage makes more water available by capturing water when it is plentiful and making it available for use when there are shortages. Storage can also be used to balance supply and demand over much shorter periods such as storing water from river flows during the night and making it available for farmers to use during the day. This not only makes available water that would have otherwise gone to waste, but it also increases the flexibility of irrigation systems by improving the reliability and timeliness of supplies so that farmers can better schedule their irrigation and reduce water losses. Groundwater storage offers similar benefits and is one of the reasons why 'water scavenger' irrigation using groundwater has been so successful in Asia. Water recharge is the link between surface and groundwater storage. Canals and reservoirs now provide opportunities to recharge groundwater and to act as a buffer between water supply and demand for irrigation (see Box 3).

Storage options have wide application and water is accessed and used in a variety of ways. In some cases the storage is managed by small farmer groups and others by larger more formal institutions. Each has its own niche in terms of technical feasibility, socioeconomic sustainability, and institutional requirements (McCartney, 2010).

The impact of storage on poverty varies considerably. In China and India there are examples of successful water storage used to improve the management of canal irrigation by providing farmers with water as and when they need it. The Sudan has a long tradition of night storage canal irrigation. There are examples of storage in reservoirs along canal systems in Nigeria. In Ghana the storage story is mixed. Some reservoirs have led to crop diversification and more stable and reliable income for farmers, whilst others nearby, under similar conditions, have failed to bring about any significant change (McCartney, 2010). This raises the importance of the context in which technology interventions are made.

## 5.2 Re-thinking canal irrigation

Canal irrigation is synonymous with surface flooding – basins, borders and furrows. On a world scale this is the most dominant irrigation technology. 95 percent of irrigation still relies on surface flooding, most of the remaining 5 percent is sprinkler irrigation and a small percentage uses trickle methods. This balance is unlikely to change in the next 50-100 years and particularly so in the LDCs. For this reason, technologies that seek to improve canal irrigation should have a high priority.

Canal irrigation, particularly in Asia is not working well and it is argued that it is no longer suitable. Smallholders, who depended on the large canal systems for their water, are finding ways around the problem by buying pumps and exploiting local groundwater, often recharged from canal seepage, rather than relying on the uncertainties of canal water. The extensive canal networks cannot be easily abandoned and replaced with small pump schemes. The challenge is to find ways of using existing canal systems by making it as responsive as groundwater irrigation.

Canals are difficult to manage hydraulically, and in many systems tail-enders suffer from a lack of water because those at the head tend to take more than their share to the detriment of those at the tail end – this is

**Box 3: Conjunctive use of a small reservoir and an aquifer**

With improved tubewell technology now available and within reach of small farmers, many storage reservoirs, which were previously used as irrigation tanks in the arid and semiarid tracts of India, have now been converted to recharge ponds and tubewells have taken the place of irrigation canals. In Tamil Nadu, India a small storage reservoir and 60 shallow tubewells enabled 53 farmers to grow one crop each year. In 1986 the farmers decided to permanently close the reservoir sluices and to use the stored water for recharging the aquifer. From then on farmers, using only water from the tubewells, have grown two crops per year over the past 14 years.

**Small and large reservoir combinations**

In China, Sri Lanka, and other countries large storage facilities supply water to numerous small tanks within a river basin. These reduce supply and demand mismatches from large reservoirs. In southern Sri Lanka, linking a large storage reservoir with five small, existing, cascading reservoirs resulted in a 400 percent increase in crop production in the command area.

*Source: Adapted from McCartney, 2010*

the classic 'top-ender, tail-ender' problem. Most major canal systems use 'upstream control' technology that can not only exacerbate the 'top-ender, tail-ender' problem but is also inflexible to changes in water demand from farmers. This was acceptable in past planned economies when engineers made decisions about how much water was delivered to farmers. But in today's demand driven economies, farmers want much more control over inputs. There are canal control systems, such as 'downstream control', that can improve flexibility and provide on-demand irrigation but this would require major re-engineering and would be costly. More local and cheaper options are possible. In the Indian state of Maharashtra a water user association has installed pipelines to replace canals in order to distribute water from tertiary canals and ensure a more equitable share of water. In another scheme, farmers have invested in a storage tank and then distribute water through specially designed equal discharge pipelines (Bhamoriya *et al.*, 2009). Indeed pipelines, although initially more costly to build than canals, can offer much better control over water supplies, making the system more responsive to farmer demands (Van Bentum, 1994). This is why most domestic water supplies use pipe systems rather than canals— the lack of control over canals would be quite intolerable for most domestic consumers.

Improving canal irrigation is not just a technology fix, but requires institutional changes. China's public canal irrigation schemes are improving because irrigation managers are being given incentives to bring their rewards in line with those of the farmers (Johnson III *et al.*, 1998).

There are also options for multi-use canal systems which provide water not just for agriculture but also for domestic, industrial and environmental purposes. However, such developments would require significant institutional cooperation across government ministries of water resources, agriculture and environment.

**5.3 Mico-irrigation technologies**

'Modern' irrigation technologies, such as sprinkler and micro-irrigation are often seen as one of the keys to increasing food production on smallholdings which make up a large proportion of the land farmed in LDCs. These technologies are not suited to the major rice growing areas in South and Southeast Asia, nor are they suited to growing staple grains. But modern methods do offer considerable potential for making best use of available water in Africa which includes 13 out of the 18 nations in the world having less than 1,000 m<sup>3</sup>/capita/day. Micro-irrigation can be targeted at selected environments where water costs are high; soil, topography and water quality make surface irrigation impracticable; high value cash crops can be grown and marketed; and where the farmer desires to increase his/her income (Cornish, 1998).

Micro-irrigation technologies are commonly used in water scarce areas in developed countries and are an intervention that has potential to use water with minimal wastage. They generally fall into two categories: low-cost technologies which are used for small plots and gardens (see below); and the state-of-the-art micro-irrigation systems which are used on large commercial agri-business enterprises mainly for high value fruit and vegetable crops. These

technologies can improve productivity, raise income through improved crop yields and outputs, and enhance household food security. However, they are not suitable for growing staple cereals.

Although micro-systems provide the potential for water saving by reducing the water wastage that often occurs with other methods such as surface flooding, these benefits are not always realised in practice. Indeed the amount of water used by the crop is the same whether the water is supplied from a micro-system, sprinkler, or a surface flooding method. Much depends on how the systems are managed rather than the systems *per se*.

Micro-systems have been extensively marketed in India among smallholders and commercial farmers for over 30 years in line with government policy but with mixed results. The systems were heavily subsidized, at times up to 90 percent of the cost, but the farmers responded moderately. Although the government provided subsidies, other factors were lacking including, ground water access, cash, crop-specific micro-irrigation technologies, know-how, and access to financing. Additionally micro-systems did not effectively reach its smallholder target group. Rather, the technology was mainly adopted by wealthy commercial 'gentlemen farmers' (IWMI, 2006).

Nevertheless, there are some areas in India where small holders have adopted the technology- even without government subsidies. Smallholders that employed micro-irrigation technologies tend to intensify their production with multiple crops or even switched to higher value crops. For instance in Maharashtra, technology adopters switched from groundnut and oilseed to high water consuming higher value crops such as cotton and bananas. Although drip irrigation increases yields and correspondingly increases income, the economic benefits need to be balanced with higher water demand, which can place greater stress on already scarce water resource (IWMI, 2006). The simple application of technologies is not sufficient to address water scarcity and may at times aggravate the situation; rather micro-irrigation solutions need to consider end-user needs and work within the societal and environmental constraints.

#### **'Affordable' technologies**

The investment costs and the inherent risks of modern technologies can be too high for many smallholders therefore a number of alternative 'affordable' technologies have been developed to

fill the gap. These include drip irrigation kits such as the *Pepsee* easy drip technology, bucket and drum kits, micro sprinklers, micro-tube drip systems and others that have been designed by NGOs such as the International Development Enterprises (IDE). They are affordable but often only at a small scale level. A drip kit covering 10m<sup>2</sup> for example may cost as little as \$10, which may be affordable. But the same level of investment on a hectare of land would cost \$ 10,000/ha, which is a very high level of investment and would be difficult to justify on a commercial basis.

Nevertheless, these technologies are characterized by affordable initial investment costs, relatively short payback periods, and high farm-level returns on investments. In addition, widespread use of small-plot irrigation methods can generate employment opportunities on and off farms in rural areas. They are somewhat labour-intensive, but local entrepreneurs can establish businesses that build, service, and repair the irrigation equipment. Such activities stimulate greater demand for farm products and other non-tradable goods and services.

Rainwater harvesting is also practised on a small scale around households and home garden to grow fruit trees, water small livestock, and support fish ponds. Techniques include collecting rainwater runoff to store in small tanks, drums, and off-stream storage reservoirs. This requires only limited investment, no regular external input, are simple to manage, and can be built close to homesteads. Additionally they fit well with the livelihoods of the rural poor.

### **5.4 Water lifting**

Few farmers and households in LDCs have the luxury of a gravity or pressurised water supply. Most smallholder and garden irrigation requires some form of water lifting and these are usually characterised by their energy source – human and animal power, fossil fuel, electricity, and renewable energy sources such as sun, wind, and water.

#### **Human powered Pumps**

Many smallholders still rely on lifting water by hand using buckets and other similar containers are also used to transport water from source to field. These simple tools, though appropriate for many, are limiting, inefficient in terms of energy use, and time consuming. They prevent the poor, particularly women (see section 6.1.1), from taking up alternative opportunities for income generating tasks.

Most hand-operated mechanical pumps are designed for domestic water supply purposes and are not well suited to the high water volume requirements of irrigation. Treadle pumps changed such views on the use of human power by transferring the driving force from the arms to the much stronger legs. They were first developed in Bangladesh in the 1980s for lifting relatively large volumes of water through small lifts of up to 1 m for rice irrigation. Its acceptance among farmers has been described as extraordinary and over 500,000 pumps are now used daily in the country (Kay, 1999). Treadle pumps are seen as a 'stepping stone' between hand lifting and motorized pumping. The initial capital cost is low, between \$50-120, thus investment is modest though not without risk.

Treadle pumps were introduced into Africa from Bangladesh in the 1990s and are now widely used across the continent. Although the current number of pumps installed is not known, it is estimated that there are many thousands used in Niger, Kenya, Zambia, Zimbabwe, and Malawi. In some countries, notably Kenya, a commercial market has been established with supply chains so that spares and pump maintenance services are available. Some treadle pumps have now been adapted to sprinkler and drip irrigation systems.

There are also those who see treadle pumps as yet another means of tying up farmers and their families into yet another form of drudgery.

The transfer of treadle pump technology from Bangladesh to Africa was not without problems. However, commercial companies and NGOS have successfully re-engineered the technology so that it can cope with the different operating conditions that prevail such as undulating land and deeper groundwater sources. Some treadle pumps have now been adapted to sprinkler and drip irrigation systems. The only fear is that such products are seen as a technological fix provided by manufacturers interested in sales thus treadle pumps may be used in situations where much simpler traditional technologies would be more appropriate.

#### **Electric and Gas Powered pumps**

The availability of: small, cheap petrol, diesel, affordable electric pumps; the development of cheap well drilling technology; rural electrification; and subsidized energy has resulted in a rapid growth in motorized pumping across the world in the past few decades. Pumps provide a level of freedom that smallholders did not have on the larger state-owned

#### **Box 4: Micro-irrigation in Kenya**

KickStart, an international non-governmental organization, developed a low-cost micro-irrigation pump which is purchased by local entrepreneurs and used to establish new, small agricultural businesses. These pumps allow users to irrigate their crops year-round and not to depend solely on seasonal rainfall.

Irrigating crops during the dry season allows pump owners to take advantage of the higher crop prices in the marketplace. Successful models of micro-irrigation in India and Nepal have increased crop yields and reduced water consumption in addition to increasing income and household food security. Since 1996 KickStart has been one of the leaders in micro-irrigation technologies through the development and sales of its manually operated "MoneyMaker" pumps. "Farmerpreneurs" are increasing their incomes by as much as ten-fold transforming subsistence farms into highly profitable enterprises.

*Source: Pandit et al, 2010*

#### **Box 5: Labour for lifting water is not always a cheap option**

A healthy farmer expends about 250 Watt-hours of energy each day and will use 1 kWatt-hour in four days. At an income of \$1 per day this would be valued at \$4. This is similar to the amount of work that a small petrol engine pump can produce with a litre of fuel at about \$1 per litre. If the labourer has alternative wage earning work then investing in a petrol driven pump can pay dividends.

*Source: Fraenkel, 2006*

### Box 6: Pumped irrigation in Nigeria

Farmers in northern Nigeria lost their traditional use of the fadamas (wetlands) along the rivers following the construction of dams to control the river floods for urban water supply and irrigation. As an alternative they turned to small-scale irrigation using shallow groundwater recharged by the river and lifting it by shadouf or calabash (hand lifting devices) in the dry season to grow vegetables for local and city markets. In the early 1970s a few farmers, with help from relatives, bought small pumps from private traders. In 1982-83 an agricultural development programme based in Kano sold over 2 000 pumps to individuals or small farmer groups. Engineers introduced low-cost well technologies from India, which reduced well construction by two thirds with a commensurate increased return on tubewell investment.

This has been one of the most successful irrigation developments in Nigeria with many thousands of pumps being used by private farmers. Maintenance is well established and farmers have confidence in the technology. However, external monitoring was necessary to avoid depletion of the aquifer.

*Source: Kay, 2001*

schemes. They can irrigate as and when crops need water and when it is convenient to irrigate- usually during the day rather than at night (Snell, 2001).

In places where there is a public supply of electric power near farmland, electric pumps can be an attractive option. But there is an uncertainty of the supply of electricity and the dependency of farmers on an unpredictable energy source. Motorised pump cost also tend to benefit large-scale farmers due to economies of scale but tend to be uneconomical for certain smallholders with limited land and revenues (Adeoti, 2009). For instance, in Ghana, the cost of the motorised pump was 5.6 times higher than a treadle pump, a high capital investment for small scale vegetable plots owners (IWMI 2005). Additionally the operational costs of motorised pumps were high compared to the returns. Often users would have to travel long distances for repair support and spare parts. Capabilities in maintenance and repair are important considerations in the adoption of motorised pumps.

#### Renewable energy powered pumps

Studies on renewable energy sources, such as solar and wind, present mix results regarding technical feasibility and costs. Some studies argue that renewable energy sources do not have the long-term and loss-free energy storage inherent in fossil fuels. The energy supply is therefore usually unreliable, while the equipment needed to capture and apply a useful amount of power to a pump for irrigation purposes is expensive (Snell, 2001; Fraenkel, 2006). However, other studies have found that some renewable sources are more cost competitive than traditional sources of energy in rural areas and for small scale applications,

as micro-irrigation (ESMAP, 2007; Burney et al. 2010).

Solar power is widely used for applications requiring relatively small power inputs in remote locations – telecommunications and small isolated potable water supplies are typical examples. Despite many years of intensive research attempting to develop cheap and robust solar energy gathering devices, they remain expensive relative to their power output, and both they and the associated equipment for bringing the energy to a pump are quite delicate and sensitive. Experience of their use in remote locations for pumping potable water has been mixed, with pumpsets often out of operation for long periods awaiting repair or spare parts, although this problem can also apply for conventional energy technologies (ESMAP, 2007; Burney et al. 2010). A study regarding solar-powered agricultural irrigation found that photovoltaic (PV) pumping irrigation systems are technically and economically feasible, but the main constraint is land availability for the solar array (Kelley, 2010). At present, solar-powered devices are only cost-effective in low-power and specialised applications. Nevertheless, they must be included on the list of potential technologies, and future improvements in cost and robustness should improve their competitiveness.

Wind power has been used extensively for lifting water, usually for draining low-lying land where there are persistent strong winds. Relative to their water-lifting output, both ancient and modern wind-powered devices are large and expensive in comparison with other technologies now available. They tend not to be very reliable, or at least need a good deal of attention and maintenance. An additional factor is the regional and seasonal availability of strong winds.

Over most of the cultivable lands of SSA wind speeds are not high for much of the year. Nevertheless, some experiences have shown that wind energy resources can be successfully used for abstracting groundwater and irrigating crops (Al Suleimani & Rao, 2000). Additionally, it has been found a great potential of windmill pumps for irrigation in places like India, taking into account conditions of the renewable resource, income of farmers, etc. (Kumar et al, 2007).

Renewable energy sources are in principle attractive for resource-poor people because the energy itself comes without financial cost or muscle-work, and they should all be included in any inventory of relevant technologies. However, the appropriateness and cost-effectiveness of a particular technology is context specific and can only be determined if the power potential and availability pattern of the renewable resource in question is adequately assessed.

The decision to use renewable energy technologies rather than conventional energy sources depends on number of factors: availability of renewable resources on the site, the power needed and type of utilization, among others. Notable examples of application of renewable energy technologies in rural areas are wind pumps for irrigation in South Africa and Namibia. Other applications include small biomass plants for water pumps, micro-hydroelectric plants and solar energy for micro-irrigation (UNCTAD, 2010). Overall renewable energy may have a role to play for small households in the rural areas but it is unlikely to significantly replace the need for fossil energy and hand powered pumping for irrigation in the foreseeable future.

### 5.5 ICT in water management

ICT is growing in importance in most LDCs and although it has yet to make a significant impact on agriculture and AWM there are positive signs. In Ugandan villages for example, farmers have access to a wealth of information on the Internet and can call their questions in to a free telephone hotline (Question Box, 2010). The operators, who speak the local language, search for the answers and call the farmers back and provide information on crop prices, weather forecasts for irrigation and water management, plant diseases, and more.

GIS (geographic information system) technology is also finding new ways of supporting water management. More than 6,000 traditional water tanks

(small reservoirs to capture rainfall or runoff) were identified in a single sub-watershed in the Krishna basin using Landsat data (Thenkabail *et al*, 2008; IWMI, 2008). The IWMI estimated that if these tanks were restored to capture just 15-20 percent of local rainfall, they could hold some 1.74 cubic kilometres of water – enough to expand the irrigated area in the region by 50 percent and at a quarter of the cost per hectare of a typical dam and diversion project proposed for the region (IWMI, 2008).

## 5.6 Common and unconventional water sources

### Wastewater re-use

Most domestic and industrial water is not consumed, rather it is used and returned to the catchment either directly discharging into rivers or seeping into groundwater. It is only lost when discharged into the sea or into the desert where it is beyond economical recovery. Wastewater is a resource that can be re-used, particularly for agriculture. In most European countries wastewater, suitably treated to a high standard, is regularly discharged into rivers where it is diluted within the main flow then re-used downstream by households, industry, agriculture and the environment.

Wastewater reuse is high on the agenda in countries across North Africa and the Middle East where water is already scarce. In the Syrian Arab Republic, 67 percent of sewage effluent is reused, in Egypt 79 percent, and in Israel 67 percent, mostly for irrigation and for environmental purposes (FAO, 2010). However, there is a continuing debate over whether this water is actually 'available' for exploitation. It is unlikely, for example, that the 0.79 billion cubic metres of effluent produced in Egypt each year is readably available for total usage. Egypt's water strategy for 2017, which shows more water being used than is available from the country's water allocation from the River Nile, suggests that this entire amount of water reuse is already accounted for in the water balance (FAO, 2010a).

Wastewater for agricultural uses is also becoming an important issue in Latin America and the Caribbean. Large cities use treated wastewater in local fruit, vegetables dairy and poultry markets. In Mexico for instance, approximately 25 percent of municipal wastewater is reused to irrigate 300,000 hectares of land (Mejia, 2010). On the other hand, in some countries culture can be a barrier to re-using

wastewater besides concerns about the quality of treatment. Using effluent to grow crops such as fruit and vegetables would be unacceptable. However, treated water used to grow processed crops such as grains and root crops and biofuels may be less contentious.

Large scale wastewater treatment for agricultural purposes can involve substantial additional costs compared to fresh water. Wastewater requires treatment to avoid health risks even when the crops are not directly consumed. Municipal wastewater comes mainly from cities and larger towns where there is a high concentration of people and industry, which may make it feasible and economically viable to invest in the required infrastructure. However, cities are often some distance from where this treated water can be used for agricultural purposes and so canals and/or pipelines will be needed to transport the water. Also the timing of wastewater availability (usually an even flow over the year) does not coincide with agricultural water demand (usually over a 3-month growing season); therefore some means of water storage will be essential if all the water is to be effectively used. All this can add considerably to the costs of re-using water for agriculture.

Wastewater usage in agriculture on an informal and unregulated basis is a pressing issue in developing countries which deserve more attention. Globally around 3-3.5 million hectares of land are irrigated with raw or diluted wastewater- double the size of Africa's total formal vegetable irrigation schemes. In many low-income countries, fresh water is not readily available and municipal wastewater treatment facilities hardly exist; thus untreated wastewater is the only affordable option for irrigation in many cases. Additionally, nutrient value in wastewater has led to increased yields, at lower costs. For instance, farmers in Pakistan on average earn 30-40 percent more per annum when using wastewater for irrigation compared to regular water. Additionally wastewater irrigation employs local supplier, traders, and others in related services. Women also benefit in sub-Saharan Africa, as they make up over 95 percent of vegetables vendors in the region (IWMI, 2006b). On the other hand, the risks to health could be extremely high. This connects the issues of food security with the major challenges facing domestic water supply and sanitation, especially in LDCs.

The issue is not whether wastewater should or should not be used in agriculture; rather, how can wastewater

be used safely for irrigation with affordable treatment technologies? The policy challenge is to maximise benefits while minimising risks in wastewater use. This would entail the adoption of safety guidelines which are appropriate to the local context, and the diffusion of simple technologies, such as localised drip irrigation, construction of shallow wells, as well as water collection and application methods which reduce contamination. There exist many innovative local solutions to wastewater treatment. In India's Kikwari village, for example, farmers constructed a wastewater system using pipes to connect the drainage water into settling tanks. The water was then filtered and used for irrigation in school and community gardens (IDE et al., 2008). The farmer field schools can play an important role in disseminating good practices and linking research with extension services. (IWMI, 2006b).

### **Desalination**

Desalination is a process that removes salt from saline water to produce freshwater. Desalination processes have developed significantly over the past 30 years and this has led to the general acceptance of two main technologies, thermal and membrane, which together account for almost 98 percent of the world's current desalination operating capacity – now in excess of 35 million cubic metres per day, much of which is in the Middle East. This is used mainly for drinking water and for industry. Estimates suggest that less than 10 percent of desalinated water is used for irrigation and this is mostly in Spain where desalination is heavily subsidised. Both processes are energy intensive and produce good quality water (FAO, 2006b).

Since the late 1970s, seawater desalination costs have decreased by 13.6 times due to economies of scale and continued developments in membrane technology; but costs for deployable technologies have remained largely unchanged since the past years (AMTA., 2007). Desalination could be a potential source of water for irrigation but at its current cost of around \$0.5-1.5 per cubic metre, the technology is still considered too costly. Some firms, however, are claiming to develop new systems that could potentially cut desalination costs by half (Hurst, 2009). There are also concerns about the water being too pure and lacking micro-nutrients for irrigation (FAO, 2006b).

Planners and policymakers still look at desalination as a 'silver-bullet' solution to water shortages but seem to miss the perverse irony – by burning more fossil

fuels, desalination will likely worsen the problem they are trying to solve while making local water supplies more and more dependent on increasingly expensive fossil fuels (Postel, 2010).

A third option involves the use of solar energy for desalination but this is very much in its infancy. Solar stills produce water vapour by mimicking the natural water cycle but over a much shorter time period. However, yields are low averaging only 2-5 litres/day and depend on sun-hours. They are a useful option for providing basic energy and water needs in remote regions where it is not possible or cost-effective to connect to the public electricity supply, and where physical water scarcity is most severe. They are small in scale, low maintenance, and have low environmental impact.

### 5.7 Improved rain-fed agriculture

Substantial improvements are possible in rainfed agriculture. But tapping into this potential requires innovative strategies to manage the sudden excesses of water and frequent dry spells. The technologies are not new. Integrating soil and water management focused on soil fertility, improved rainfall infiltration, and water harvesting can significantly reduce water losses, improve yields, and water productivity; the strategy is to get 'more crop per drop'. The greatest potential for improvement lies in those areas that face the greatest water challenges and where most of the hunger and poverty exists.

Soil and water conservation measures can help to make better use of rainfall by increasing water infiltration and water storage in the soil. They include terracing, contour bunds, infiltration pits, tillage, integration of tree crops, and green manuring. These techniques require little or no capital investment. But the challenge for the poor is to identify pragmatic options for gradual improvement which are manageable by part-time farmers with limited skills and access to regular extension advice.

Because the majority of the world's poor and hungry live on rainfed farms in South Asia and sub-Saharan Africa, raising farm productivity using these techniques would directly boost food security and incomes. So it is both disappointing and of great concern that these technologies, though widely known, are not being extensively promoted, implemented, and practised (UNCTAD, 2011).

### 5.8 Conservation agriculture

Conservation agriculture is not directly a water technology but improved water management is one of the benefits. The rainfed farming system is practised on 95 million ha worldwide, primarily in North America, Brazil, Argentina though to a much lesser extent in Africa and Asia. Conservation agriculture utilises soil and agro-ecosystem resources in a sustainable manner in order to optimise crop yields rather than exploit natural resources to maximise output. Soil cover is permanently maintained with minimal soil disturbance using 'zero-tillage' systems. Crops residues protect the soil which enhances soil and water conservation and improves soil organic matter. This in turn improves water infiltration and storage in the soil during rainfall events.

In Africa the method is only beginning to spread in Kenya, the United Republic of Tanzania, and Zambia where some farmers have doubled or even trebled grain yields. In Zambia, conservation agriculture has helped vulnerable households to survive drought and livestock epidemics. More than 200,000 farmers are now using this technique. In the 2000–01 drought, farmers who used conservation agriculture managed to harvest one crop, while others farming with conventional methods faced total crop failure. In Ghana, more than 350,000 farmers now use conservation agriculture (IFAD, 2008).

## 6. What needs to be done?

Existing AWM technologies are available to help meet the challenge of food security. But history has shown that exploiting the endowed potential of water and land will be challenging and investing in water alone will not increase food production. Agriculture requires many and varied inputs. Complementary investments are needed in a wide range of farm products and services – fertilizer, seeds, farm power, micro-credit, good roads, post harvest infrastructure, access to markets – and conducive institutions that support farmers and empower them to take responsibility for their livelihoods. When taking these factors into account, food security becomes an extremely complex issue. Indeed this complexity was one of the main reasons why the development community pulled out of irrigated agriculture in sub-Saharan Africa in the 1960s and 1970s following disappointing investments in irrigation infrastructure.

Most industrialized countries have the infrastructure,

### Box 7: Water harvesting in the United Republic of Tanzania

Micro water harvesting systems were introduced into the drier regions of the United Republic of Tanzania to improve maize production giving smallholders more control over their farms. However, when they were invited to evaluate the micro-catchment trials, farmers understood the benefits of rainwater harvesting but were reluctant to adopt the system. They were more interested in the greater potential of using macro-catchment systems and argued in favour of more ambitious attempts to harvest runoff on a larger scale. So far the limited trials with macro systems for maize are mixed. Proper control over distribution of harvested runoff within the cropped area can be problematic for deficit-irrigated crops. There was also clear evidence that failure to provide proper control over the distribution of runoff can lead to serious erosion. Too much water can be as big a problem as too little. The need for cooperative group action can also give rise to disputes over water sharing. Whether farmers will continue to prefer macro-systems over micro-systems, as they acquire more experience in using them for maize production, remains to be seen. However, one significant outcome of the research is that the United Republic of Tanzania Government sees runoff as a beneficial resource rather than just a hazard which causes soil erosion. Development of rainwater harvesting is now included in the United Republic of Tanzania National Water Resources Management Policy.

Source: Hatibu, 1999

strong institutions, and the capacity to sustain the levels of water and food security they currently enjoy. But most LDCs lack these essential physical and social structures that underpin sustainable development. Until recently agriculture and food have not been high on the international and political agenda, not only in the LDCs but also in OECD countries. Water management has not featured high in the agriculture agenda. Farmers and professionals in LDCs lack the capacity to plan, manage, and implement AWM and there are few supporting institutional structures. Furthermore the broad socio-economic environment in which these individuals and their institutions work is not always conducive to strong market-led agricultural development.

Funding is also crucial. Asian governments initiated their green revolution in the 1970s by spending 15 percent of their annual budgets on agriculture. The World Bank estimates that a 1 percent increase in agricultural GDP in Africa will reduce poverty by 3 or 4 times as much as a 1 percent increase in non-agricultural GDP. Yet donor countries spend less than 5 percent of their development aid on agriculture in the region (HOC, 2009).

On the positive note, agriculture is now returning to the world agenda and the international community is beginning to re-engage in agricultural investment. There is now a growing recognition that integrating resource management, production, marketing, and consumption, is essential for sustainable and profitable agricultural growth. But 'more of the same' will not be enough and the pitfalls of the past must be avoided.

### 6.1 Focus more on women

Given the important role women play in agricultural production in LDCs, focusing on the unique challenges women face and their lack of access to resources is an important key to increasing overall agricultural productivity (Meinzen-Dick, 2010). Women are often excluded from decision-making and have little choice over the services they receive. They have limited access to water and this is often coupled with their limited access to land. Securing access to land among poor farmers, particularly women, can lead to secure access to water rights (IFAD, 2001).

Agricultural productivity is often lower for women because they have limited access to a wide range of physical assets including agricultural inputs, technological resources, and land. Thus a broader understanding of their needs is essential in order to remove the obstacles that women face. If the resources accessible to men were made equally available to women, they would increase their farm output by 20-30 percent. On the global scale, agricultural production would raise by 2.5-4 percent. As both research and extension in LDCs are dominated by men, more resources need to be directed towards women in order to narrow the gender gap in AWM (FAO, 2011).

Whilst women's role in agriculture is becoming more recognised, many AWM activities are still associated with men. For instance, the opening and closing of gates and the physical application of water in the fields are viewed as masculine tasks even in situations where women provide most of the labour in the irrigated fields (IFAD, 2007). Furthermore, men

often attend to cash crops and livestock while women are associated with tending staple crops, vegetables and kitchen gardens. Thus garden irrigation has become an important focus for women who farm vegetables for home consumption and the local markets. Studies in Nepal (Upadhyay, 2005) show that women play a predominant role in drip-irrigated vegetable production. They contribute almost 90 percent of the total labour and yet the extension and adoption system focuses largely on male farmers and community leaders. Women have received little or no information on improved agriculture and technology. If irrigation is to address the concerns of both men and women, then women should be included in the management of local water resources through Water User Associations (WUA).

#### **Women in WUAs in Ghana**

In Ghana an IFAD-supported water management project established a WUA in which 40 percent of the participating farmers were women. They were allocated 40 percent of the land with plots the same size as those allocated to men even though women were not traditional land owners in the region. Women now play a much greater role in irrigation management, they have direct access to irrigated land, equal time to speak up and present their views, and they generate crops and cash which contribute to family food security and improved nutrition

*Source: Hatibu, 1999*

IFAD (2007) also recommends new ways of doing business enabling women to benefit from water projects. This includes fixing minimum quotas for land allocation to women and ensuring equal plot sizes for men and women, improving women's access to financial services, providing additional water infrastructure such as wells and handpumps, opening up membership to users of water other than irrigation,

and establishing a minimum quota for women's membership of WUAs.

Multiple-use schemes offer opportunities for women to improve their overall wellbeing and that of society by providing additional uses for water rather than single uses. The public sector was responsible for creating these water sub-sectors and categorizing water uses for single purposes (IRC and IWMI, 2009) which artificially split up people's interests when in practice communities naturally use water for a variety of purposes. Multiple-use schemes recognize that water has many applications and priorities such as domestic use, kitchen gardens, livestock watering, and fisheries, many of which are traditionally the responsibility of women.

#### **Adding domestic water use to an irrigation scheme in Nepal**

The Nepal Smallholder Market Initiative (SIMI), a multiple-use scheme was introduced in Nepal from 2004-2008. Small stream diversions and water collection tanks were installed to provide a gravity water supply to surrounding village reservoirs for 10-40 households for homestead horticulture and domestic uses. Some households started using drip irrigation. The cost of this multiple-use system was approximately \$50/year per household while the benefits from yielding high-value crops increased income by more than \$180/year on 0.5 ha plots of land

*Source: Winrock; IWMI, 2006; IDEet al., 2008.*

Add-ons to irrigation schemes can include steps to irrigation canals to enable access for drinking water, laundry and other domestic activities, or simply maintaining water in seasonal irrigation canals throughout the year for domestic uses. Similarly, schemes primarily designed for domestic uses can become multiple-use schemes (or 'domestic-plus' schemes). For instance, if 50 – 100 litres per capita

#### **Box 8: Women farmers innovate to solve their irrigation problems in Ghana**

A small-scale irrigation project was established on the outskirts of Khumasi for a group of women growing vegetables for the local markets. The scheme uses open irrigation channels supplying many plots, less than 0.1 ha each owned by a different person. The scheme was designed and built to supply water on a rotational basis and each woman was given an allotted time when she would receive water. The women objected to the scheme and said that the rotation was unworkable because they had other household and family duties that took priority over irrigation. They solved the problem by innovatively building small storage tanks on their farms. This allowed them to receive water when it was available and to irrigate their crops when it was convenient to them.

*Source: Kay, 2001*

per day are provided, 3 litres per capita per day is designated for drinking and cooking. The water in excess of domestic needs is used for horticulture, livestock, or small-scale enterprise. Additionally multiple-use schemes recognize women's concurrent roles as agricultural decision makers, housekeepers, livestock keepers, and entrepreneurs. Hence by their very nature multiple-use schemes should be participatory and community-driven. Planners look at *all* users' priorities for *all* water applications and sources instead of the single-use public sector mandate. Moving beyond the sectoral boundaries of the single-use water subsectors, this 'inclusive community-based participatory planning' approach involves men and women alike, leading to a more 'gender-balanced water intervention' (IWMI, 2006).

Overall, gender perspectives need to be mainstreamed in planning processes and not only in multiple use schemes to ensure the specific needs and concerns of women and men from all social groups are taken into account in the development, use, and management of water.

## 6.2 Focus on existing technologies

Most benefit will come from promoting and using existing technologies and adapting them to new circumstances, rather than developing new technologies. This is true for both irrigation and drainage technologies. Adapting existing technologies should embrace 'design for management' as many technologies are designed and developed with little thought given to who will manage them, how they will be managed, and maintained. This is not a new theme, rather it was promoted in the 1980s to improve irrigation performance. It is still highly relevant today. Pumped irrigation schemes in Morocco were recently

designed and built without considering on how they would be operated. The result was poor energy use efficiency because the schemes were operated well below their design capacity and farmers had to bear the unnecessarily high fuel costs.

Design for management also needs to be gender sensitive to enable rural women to fully benefit from schemes. Designs should be based on the actual situation at a particular site and not just on commonplace assumptions about the role of women and their control over and access to resources. Examples include preferences for irrigation schedules that fit better with family duties and avoiding night irrigation because of gender-based violence or harassment can be important issues.

In Zimbabwe, although women were the main irrigators, only men were made responsible for and trained to operate and maintain the diesel pumps for water supplies. This lack of control over the supply often meant that women experienced the additional burden of carrying water to ensure their crops were irrigated. Designing schemes using existing technologies for multiple uses can also reduce drudgery and provide women with more time for other productive activities (IFAD, 2007).

## 6.3 More research for development and better dissemination

There is often a disconnect between AWM research in LDCs and its practical implementation for farmers. Some research topics may not be relevant for farmers while other research outputs may be beneficial but do not necessarily reach its intended audience. New ways of disseminating this information are needed which take into account the needs of end-users. The

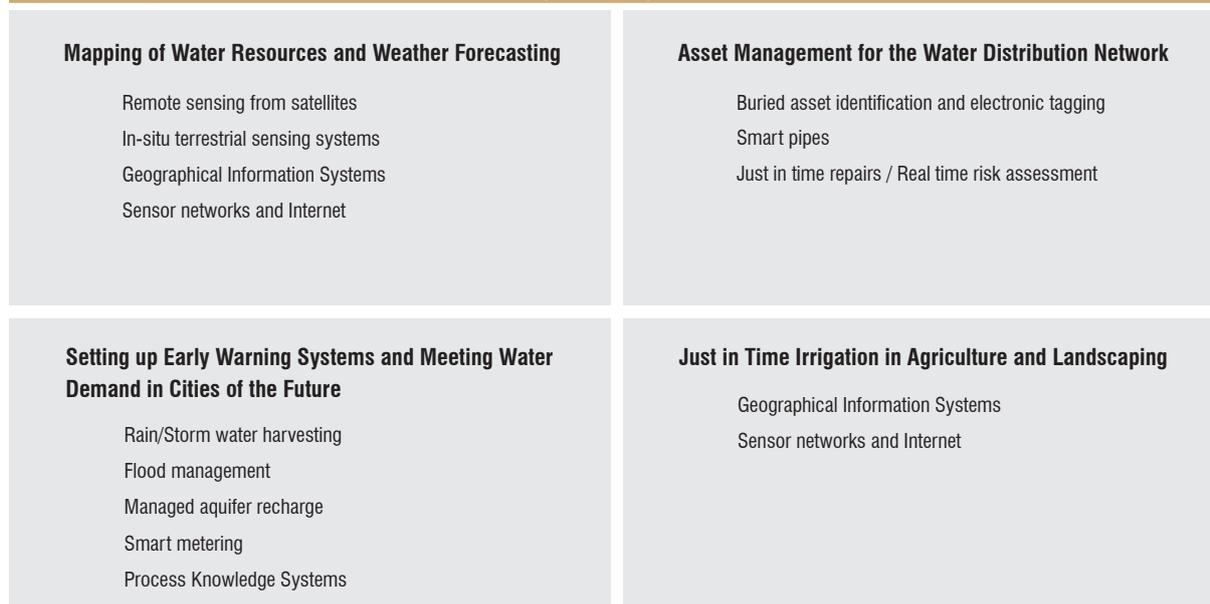
### Box 9: Women in agriculture

According to the Africa Regional Review, "Successful extension must involve women, youth and the most vulnerable people in the rural communities."

Source: Mokwunye, 2009 in Meinzen-Dick, 2011

In workshops in West Africa and North Africa the consensus was "Women have many roles in agriculture: farm production, marketing, food preparation, etc. Evidence shows that empowering women will result in [lower] child mortality, school enrolment and declines in child malnutrition. Women also have a better track record in collaboration and sustaining social capital. Based on evidence from micro-finance schemes, investments used by women have shown higher returns as those used by men"

Source: Smets, 2009 in Meinzen-Dick, 2010

**Figure 3. Major areas for ICT in water management (ITU, 2010)**

Source: ITU, 2010

information should not only be intended for farmers but also presented in an appropriate manner for policy-makers, agro-entrepreneurs, extension staff, and the general public. In East Africa, researchers are encouraged to focus on uptake and the approach is to build a 'community of champions', now totally over 800 whose role is to promote AWM with a carefully prepared uptake promotion strategy (NRSP, 2006). Researchers in natural resources need to bring social scientists into the team so that their efforts are more end-user and gender responsive.

NGOs also have a vital role to play in linking research with practice. They have the advantage of directly interacting with the local community. Researchers should engage more directly with NGOs to better understand the local needs, gain feedback and share information.

#### 6.4 Smarter water management

One of the biggest untapped potentials for smarter water management in all types of enterprises lies in more creative use of information technologies such as meters, sensors, controllers, computers, and even cell phones. These may seem hi-tech options but in view of the rapidly expanding use of cell phones in LDCs there is scope here to provide valuable information

and advice to farmers in remote places who do not have access to extension services.

Areas in which ICT can play an important role in water management are shown in Figure 3.

Special efforts should be made to reduce gender gap in ICT access and use, particularly in view of the significant role that women play in agriculture (Melhem et al, 2009) (see section 6.1).

#### 6.5 Build new institutions

New gender-sensitive institutional arrangements are needed which centralize the responsibility for water regulation yet decentralize water management responsibility and increase user ownership and participation.

At a national level, monitoring, collecting, and synthesizing data on water resources is an essential part of managing and regulating water resources. So too is communication across government departments with water management responsibilities. Bridges need to be built between the various ministries that deal with water, food, agriculture, environment and finance. In too many countries responsibility for water in agriculture falls between the Ministry of Agriculture, which deals with agricultural water management and

### Box 10: Strong social capital supports tradition rice irrigation

Traditional rice irrigation terraces in South East Asia rely on strong social capital to organize and manage labour-intensive construction and maintenance of the terraces and to synchronize cropping patterns for effective water and pest management. Without strong social capital this system would not survive.

Source: NRESP, 2003

the Ministries of water resources, irrigation, and the environment which deal with other water matters. Communication between ministries and other bodies involved in water management will be an essential ingredient in integrated water resources management.

Decentralization is a key policy for many LDC governments but local management relies on sustainable local institutions capable of engaging local communities and articulating their needs as well as analyzing, designing and implementing policies and innovations. The essence of such organisations is social capital, which will need strengthening if decentralization is to succeed.

While there is broad consensus on these principles among international organisations, there is still a long way to go to get this adopted politically by national policy-makers and transformed into operational and context-specific strategies.

### 6.6 Develop AWM capacity

A key constraint to developing water for agriculture in most LDCs is the acute lack of capacity at all levels. Capacity development is not just about training farmers, local professionals, and government-based research and extension service personnel who provide services to farmers; it is also about developing the institutional structures within which people can work, such as water abstractor groups, extension support services, and providing a favourable socio-economic environment which actively promotes a policy of increasing food production and in which agricultural water investment can flourish. For example, reducing tariffs on imported pumpsets or other irrigation and soil improvement technologies would help to lower costs and make agriculture more profitable (FAO, 2004).

Building capacity is a long, slow process of dialogue, coordination, participation and knowledge sharing among farmers, the state, finance and donor organizations, non-governmental organizations, community based organizations and research centres.

### 6.7 Support Public-Private-Partnership

Public Private Partnerships (PPPs) operate in some LDCs and offer a new approach to irrigation development by involving the private sector in smallholder farming in traditionally government/aid funded activities. These need not be two separate sectors of the economy. Rather there are opportunities for cooperation between the two and for smallholders to join with commercial farmers for a potential 'win-win' situation.

In Zambia smallholders and emerging commercial farmers are encouraged to cooperate (Tardieu, 2009). Smallholders can benefit from accessing the value chain and acquiring more knowledge on modern farming techniques and management skills. Commercial farmers benefit from economies of scale, being able to purchase crops from neighbouring smallholders, and adding value such as maize milling and bio-fuel processing. Including smallholders in commercial irrigation schemes can also reduce unit water costs. The approach is based on three principles: irrigation schemes must be financially sustainable- particularly for smallholder schemes; they must be professionally managed; and there must be inclusive business opportunities for both input supply and for marketing produce.

The approach is not without its challenges, not least of which is the limited technical and commercial capacity within the government bodies in Zambia to engage in PPP with private stakeholders and financial partners. But valuable lessons for success have already been learned including: making sure the schemes are large enough (250-1,000ha) to be professionally managed and financially sustainable; joining irrigation and marketing service provision as a way to mitigate financial risks; and addressing the lack of competent private operators in the irrigation sector.

### 6.8 Encourage the private sector

Much of AWM developments around poverty are based on aid. But there are considerable opportuni-

ties for the private sector to engage commercially in the supply of water management technologies. India provides an example of how this can be done (as seen in section 5.1 Box 3). Africa can learn a great deal from this as there are considerable opportunities to introduce affordable, appropriate pumps manufactured or assembled locally. Similar opportunities exist for the supply of drip kits and treadle pumps and the development of supply chains that offer support and spare parts.

To be commercially successful, products must make a significant positive contribution to the income and productivity of the poor customers who buy them; they should be cheap enough to be affordable; have a very short payback period; and match specific customer requirements such as fitting the small plots typically farmed by smallholders.

### 6.9 Focus more on youth

Over 25 percent of the world's population is between 10 and 24 and in some African countries it is 35 percent – most are born into poor rural families. Youth is largely 'invisible' in natural resources development yet their potential for contributing to economic growth and food security is significant. It is argued that the time has come to mainstream youth in natural resources related development policies and to put aside the 'received wisdom' that the young are not interested in deriving a livelihood from land and water resources (NRSP, 2004).

### 6.10 Increase water-food trade

Some 85 percent of the water used by the world's half billion or so farms produces food commodities that remain within the producer economies. Only 15 percent of farm output in terms of embedded water is traded internationally and meets the food and water needs of over 70 percent of the world's 200 or so water deficit economies. This trade in water is embedded in food products; 'virtual water' between water-rich and water short nations will play an increasing role in enabling better distribution of food to countries that find it difficult to grow sufficient staple food crops. But the aquapolitics of importing food versus self-sufficiency will not be easy to resolve. Poorer countries may wish to continue over-exploiting water resources to feed their populations. Industrializing the economies of water-scarce countries is seen as a long term means of raising GDP in preference to a continuing dependency on

agriculture and particularly low-value food and fodder crops (World Bank, 2007).

### 6.11 Strategy in Asia

In Asia new strategies for improving agricultural water management are being established. A useful 5-point strategy is outlined as follows (Mukherji, 2009):

- Modernizing yesteryear's schemes for tomorrow's needs.
- 'Going-with-the-flow' by supporting farmers' initiatives.
- Looking beyond conventional participatory irrigation management and irrigation management transfer recipes.
- Expanding capacity and knowledge.
- Investing outside the irrigation sector.

### 6.12 Strategy in Africa

In sub-Saharan Africa the 'Comprehensive Africa Agriculture Development Programme' (CAADP) established by the New Partnership for Africa's Development (NEPAD) in 2002 has set the agricultural development agenda for the whole region with a pillar focusing on land and water development. A group of key donor agencies have now set out an implementation strategy that promotes institutional and policy reforms and investment in viable and sustainable projects. In response to this the African Minister's Council on Water (AMCOW) called on NEPAD to inaugurate a new partnership – Agricultural Water for Africa (AgWA) – that would re-engage African countries, donors, and regional and international organisations in the development of water for food production, economic growth and poverty reduction. This partnership is now being actively developed and its mandate includes (AfDB et al, 2007):

- Advocacy – AWM needs strong positive message such as water for food, water for wealth, water for life if AWM is to be more effective. Advocacy for AWM is an immediate priority.
- Mobilizing resources – providing an authoritative platform to influence investments decisions and promote the allocation of more funds towards AWM.
- Sharing knowledge – facilitating the exchange of experience and learning with a view to improving sector performance.
- Harmonizing partner programmes – this is seen as critical to capturing synergies, taking advantage of

complementarities, avoiding duplication of efforts and, ultimately, enhancing development impact and sustainability of investments.

### 6.13 Strategy in Latin America and the Caribbean

Whilst Latin America and the Caribbean is one of the few regions in the world with sufficient land and water available to increase agricultural production, this potential is being jeopardized by high rates of natural resources degradation (FAO, 2010b). From an agricultural water management perspective the key regional issues identified include:

- A need to significantly improve agricultural productivity in parts of the region.
- The development of less water intensive and more drought tolerant crops.
- Optimization of water storage and distribution of

water using on-demand water supply systems.

- Protecting irrigated areas from flood damage and maintaining drainage systems.
- Introducing more water-efficient growing practices.
- Improving water governance and institutional capacities to ensure that existing plans function properly.

## 7. Where, for whom, and how?

The experience of agency and government-led interventions has shown mixed results and a critical gap exists between planning and successful implementation. Approaches focus too much on *what* needs to be done, less on *where* and with *whom* and most importantly *how* to implement it. Implementation is largely ignored as decision-makers and donor agencies rarely address the full complex interactions

Figure 4. The growing complexity of managing irrigation systems (Huppert, 2009)



Source: Huppert, 2009

**Box 11: How to intervene – a case study in the Jordan valley**

The Jordan Valley Authority (JVA) ensures irrigation water delivery to farms by opening and closing valves at each farm which are installed in enclosed concrete boxes. This was perceived as a complex task as the valves must be operated by qualified staff to meet the diverse cropping patterns in the valley. Because of staff constraints this proved difficult to manage and the unpredictability of the water supply due to unforeseen water scarcity added to the problems of managing the supply. Since there was little or no interaction with farmers throughout the process, some farmers would break the boxes and open valves to access the water. JVA rebuilt the boxes and tried to prevent farmers from illegally opening valves but this was unsuccessful.

In recent years JVA has realized that water delivery under conditions of diverse cropping patterns and unpredictable water supplies is a complex service requiring much greater interaction with farmers. Water user groups were established to work with JVA staff and to take responsibility for operating valves and allocating water among themselves in periods of scarcity and uncertainty. As a result it has been possible to establish a continuous process of balancing farmers' needs and actual water availability and to have the farmers themselves organize water delivery to the farms. Damage to valves and boxes is no longer a problem.

*Source: Adapted from Huppert, 2009*

between individuals, the state, and service providers, and the limited absorptive capacity to translate plans into practice.

There are no simple universal 'blue print' solutions as technology choices depend on local people and circumstances. But having selected appropriate interventions for specific locations and target groups, how can government and agencies successfully intervene in complex and changing AWM systems with specific technical, environmental, socio-economic, and institutional challenges? Recognising that AWM systems are complex is an important step to realising that AWM is embedded in the wider political and socio-economic fabric of civil society (Figure 4). These factors can make intervention complicated to implement but ignoring it can lead to rigid systems that cannot respond to change.

Some interventions are relatively straightforward, such as canal maintenance, which may indeed succeed with a conventional approach. But changing agricultural production from rainfed to irrigated agriculture is much more complex and requires a great deal of interaction between individuals and between organisations. These more complex interventions will place new demands on AWM service providers, who will need skills to work as facilitators, moderators, and change agents, and farmers who must become responsible managers, rural entrepreneurs, and citizens and that go beyond the conventional demands of participation (Huppert, 2009).

Improving AWM in LDCs is usually based on the assumption there is good governance and a

supportive institutional framework. This is not usually the case. Introducing new formal institutions such as Water User Groups within local social structures can be challenging as the local organisations often reflect traditional, indigenous, and local norms which can clash with urban institutions biased towards the interests of consumers and non-agricultural sectors. Furthermore, introducing improved AWM is often done on 'pilot' scales where subsidy schemes for replication and up scaling of successful experiences are not within the fiscal realm of LDCs.

Some agencies are now learning how to intervene in such complex issues. In Bolivia for example, local institutions are strong but national ones are weak, and a 'top down' approach to modernizing irrigation schemes in Cochabamba was not successful. A more successful, alternative strategy was adopted which built on local institutional strengths and engaged with local farmers and communities using indigenous knowledge and recognizing local water rights (Huppert 2009).

## 8. Conclusion

This paper has set out the challenges facing those LDCs where food and water security are most acute. The general consensus is that there is enough water to meet this challenge. Technology can provide the tools for the job; it is up to the various stakeholders, smallholders, researchers, policy-makers, and governments, to find innovative ways of using them wisely. Carrying on with the 'business as usual' model is not an option.

**Some key messages:**

Water scarcity is becoming a major issue not just in LDCs but also in OECD countries as well, driven by global warming, population growth, and social and economic change.

Agriculture uses 70 percent of the world's available water resources thus the wise use of water for agriculture is a key to water and food security, economic growth, and poverty reduction in LDCs.

These facts about water for agriculture are not well understood by the general public and indeed many development professionals. AWM needs a much stronger, coordinated voice both nationally and internationally so that it can get the attention and investment it deserves.

Agricultural development in the LDCs is mainly in the hands of smallholders, most of whom are women. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. Women have only limited access to a wide range of physical assets such as agricultural inputs, technological resources, land and water, and lack the capacity to deploy them. As a participatory and community-driven approach, multiple-use schemes provide greater opportunities for women by recognizing their concurrent roles in the agricultural sector and addressing their needs in water allocation and management.

Most benefits will come from using existing technologies and adapting them to new situations so they are appropriate in terms of location, people, and

purpose. Investment in water technologies must also form part of a comprehensive investment in a range of farming and value chain market-oriented services.

Research must focus on this process of adaptation and innovation rather than on developing new technologies *per se*. Researchers must also focus more on uptake and dissemination of information and tailor it for different audiences including farmers, policy-makers, extension services, schools, and the general public.

New institutions are needed which centralize the responsibility for water regulation yet decentralize water management responsibility and increase user ownership and participation of smallholders.

Many LDCs have a severe shortage of capacity for AWM. But this is more than just training individuals; it must embrace institutional development and the creation of an enabling socio-economic environment in which agriculture can flourish.

Public Private Partnerships offer new opportunities to improve agricultural water management as well as the prosperity of smallholders.

Institutional structures and technologies that recognise the key role that women play in agriculture are required. So too is a recognition of the role that youth can and must play in the future management of natural resources.

There is an abundance of good advice on *what* needs to be done. But the question of *how* to do it is rarely addressed. A new pro-poor approach to AWM is needed which addresses both *what* to do and *how* to do it if interventions are to benefit poor people.

**NOTES**

<sup>1</sup> FAO (1992) defined safe food as follows: "food supply must have an appropriate nutrient content and it must be available in sufficient variety and quantity. It must not endanger consumer health through chemical, biological and other contaminants and it must be presented honestly."

<sup>2</sup> Bruinsma (2009) produced similar predictions for 2050

<sup>3</sup> South Asia: India, Pakistan, Bangladesh, Nepal, Sri Lanka, Bhutan, Maldives and Afghanistan  
East Asia: China, Japan, Mongolia, Democratic People's Republic of Korea and Republic of Korea  
Southeast Asia: Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Thailand, and Viet Nam  
Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan.

<sup>4</sup> IFAD defines supplemental irrigation as "the addition of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields"

---

## REFERENCES

- Adeoti, A. (2009). Factors Influencing Irrigation Technology Adoption and its Impact on Household Poverty in Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. 109 (1): 51–63.
- AfDB, FAO, IFAD, IWMI, and WB (2007). Investment in agricultural water management for poverty reduction and economic growth in sub-Saharan Africa. Synthesis report. Washington, DC.
- AMTA. American Membrane Technology Association (2007). Membrane Desalination Costs. <http://www.asiawaterproject.org/water-crises/water-facts/surface-water-pollution/>
- AWP. Asia Water Project (2010). <http://www.asiawaterproject.org/water-crises/water-facts/surface-water-pollution/>
- Bates, BC., Kundzewicz, ZW., Wu, S., and Palutikof, JP, Eds (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change*. IPCC Secretariat, Geneva. 210.
- Bennington, J. (2009). Food, energy, water, and climate: a perfect storm of global events. [Berr.gov/assets/biscore/goscience/p/perfect-storm-paper.pdf](http://www.berr.gov/assets/biscore/goscience/p/perfect-storm-paper.pdf)
- Bhamoriya, V., Gandhi, VP. and Namboodri, NV. (2009). Irrigation Management Reforms and Participative Irrigation Management in India: A Review of the Strategy and Experience, Draft paper submitted to International Water Management Institute. Colombo.
- Bruinsma, J. (2009). The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050? Prepared for the FAO Expert Meeting on “How to Feed the World in 2050”. Rome. 24-26 June.
- CA, Comprehensive assessment of water management in agriculture (2007). *Water for food, water for life: A comprehensive assessment of water management in agriculture*. Earthscan, London, and International Water Management Institute. Colombo.
- Conway, G. (1997). The doubly green revolution: food for all in the twenty-first century. Penguin books. New York.
- Cornish, G. (1998) Modern irrigation technologies for smallholders in developing countries. IT Publications. UK.
- Dixon, J., Gulliver, A. and Gibbon, D. (2001). *Farming systems and poverty*. FAO Rome and World Bank. Washington, DC.
- Falkenmark, M. and Rockstrom, J. (2006). The new blue and green water paradigm: Breaking new ground in water resources planning and management. *Journal of water resources planning and management*. ASCE. May/June.
- FAO, Food and Agriculture Organization (1992). World Declaration on Nutrition. Food, Nutrition and Agriculture - 5/6 - International Conference on Nutrition. Rome.
- FAO, Food and Agriculture Organization (2002). Agricultural drainage water management in arid and semi-arid areas. Irrigation and drainage paper 61. Rome.
- FAO, Food and Agriculture Organization (2004). *Capacity development in irrigation and drainage*. Water Report 26. Rome.
- FAO, Food and Agriculture Organization (2006a). World Agriculture: Towards 2030/2050 Interim Report. Rome.
- FAO, Food and Agriculture Organization (2006b). Water desalination for agricultural applications. Land and Water Discussion Paper 5. Rome.
- FAO, Food and Agriculture Organization (2007). *Gender and food security: Facts and figures*. Rome.
- FAO, Food and Agriculture Organization (2008). FAO Land and Plant Nutrition Management Service.
- FAO, Food and Agriculture Organization (2009). *The State of Food and Agriculture*. Rome.
- FAO, Food and Agriculture Organization (2010a). AQUASTAT online database: <http://www.fao.org/nr/aquastat>
-

- FAO, Food and Agriculture Organization (2010b). Global and regional emergency issues: risk management and reactions to emergencies in the agriculture, forestry and fisheries sectors in Latin America and the Caribbean.
- FAO, Food and Agriculture Organization (2010c). <http://fao.org/nr/water>
- FAO, Food and Agriculture Organization (2010d). Food Outlook Global Market Analysis. Rome.
- FAO, Food and Agriculture Organization (2011). The State of Food and Agriculture. Women in Agriculture: Closing the gender gap for development. Rome.
- Fraenkel, P., and Thake, J. (2006) *Water lifting devices. A Handbook*. 3<sup>rd</sup> edition. FAO Rome and ITP Ltd UK. ISBN 18-5-339538-2
- Hatibu, N. (1999). Special issue on rainwater harvesting for crop production in semi-arid Tanzania. Tanzania J. Agriculture Science. 2 (2), P113 ISBN 0856-664X.
- Henri T., Onimus, F., and Mulenga, B. (2009). Profitable smallholder irrigation in Zambia: Is this a contradiction in terms? PPIAF Gridlines (in press).
- HOC, House of Commons (2010). *Why No Thought for Food? A UK Parliamentary Inquiry into Global Food Security*. House of Commons. London.
- Huppert, W. (2009). Coping with complexity: Innovative approaches to an emerging issue in agricultural water management. Innowat. International Fund for Agricultural Development. Rome.
- Hurts, T. (2009). Engineered Osmosis: Revolutionizing Saltwater Desalination. <http://cleantechnica.com/2009/02/22/engineered-osmosis-revolutionizing-saltwater-desalination/>
- IFAD, International Fund for Agricultural Development (2001). *Rural poverty report 2001: The challenges of ending rural poverty*. Published for IFAD by Oxford University Press.
- IFAD, International Fund for Agricultural Development (2006). Upper east region land conservation and smallholder rehabilitation project (Lacosrep), Phase II: Interim evaluation report.
- IFAD, International Fund for Agricultural Development (2007). Gender and water. Securing water for improved rural livelihoods: the multiple-uses systems approach. Rome.
- IFAD, International Fund for Agricultural Development (2008) *Water and the Rural Poor Interventions for improving livelihoods in sub-Saharan Africa* Ed. Jean-Marc Faurès and Guido Santini. With FAO.
- IFAD, International Fund for Agricultural Development (2009a). Knowledge profiling: Promoting easy access to know and experience generated in projects and programmes. With GTZ.
- IFAD, International Fund for Agricultural Development (2009b). Learning and knowledge on innovations in water and rural poverty. InnoWat [www.ifad.org/english/water/innowat/index.htm](http://www.ifad.org/english/water/innowat/index.htm)
- IFAD, International Fund for Agricultural Development (2009c). Smallholder Farming in Transforming Economies of Asia and the Pacific: Challenges and Opportunities. Discussion Paper prepared for the Thirtythird session of IFAD's Governing Council. 18 February.
- IFAD, International Fund for Agricultural Development (2011). Rural poverty report. New realities, new challenges: new opportunities for tomorrow's generation. Rome.
- IFAD, International Fund for Agricultural Development website. Supplemental irrigation. <http://www.ifad.org/rainfedag/irrigation/index.htm>
- IRC International Water and Sanitation Centre and IWMI (2009). Climbing the Water Ladder: Multiple-use water services for poverty reduction. The Hague.
- ITU, International Telecommunication Union (2010). *ICT as an enabler for smart water management*. Technology Watch Report.
- IWMI, International Water Management Institute (2005). Reducing Poverty through Investments in Agricultural Water Management. Working Paper 101.
- IWMI, International Water Management Institute (2006). *Multiple-Use Water Services to Advance the Millennium Development Goals*. Research Report 98.
-

- IWMI, International Water Management Institute (2006b). *Recycling Realities: Managing health risks to make wastewater an asset*. Water Policy Briefing. Issue 17.
- IWMI, International Water Management Institute (2007). *Recognizing informal irrigation in urban and peri-urban west Africa*. Policy Brief 26. 6.
- IWMI, International Water Management Institute (2008). *A Global Irrigated Area Map (GIAM) Using Remote Sensing at the End of the Last Millennium*. Colombo, Sri Lanka.
- IWMI, International Water Management Institute (2009). *Rainfed Agriculture: Unlocking the Potential*. Oxfordshire. UK.
- Johnson, III SH., Svendsen, M., and Zhang X. (1998). Changes in system performance in two Chinese irrigation systems as a result of organizational reforms. *Irrigation and Drainage Systems* 12: 289–309.
- Kay, M. (2001). Smallholder irrigation technology: Prospects for sub-Saharan Africa. IPTRID-FAO. Rome.
- Kay, M., and Brabben, T. (2000). *Treadle pumps for irrigation in Africa*. Knowledge Synthesis Report no 1. October. IPTRID FAO. Rome.
- Keller, A., Sakthivadivel, R., and Seckler, D. (2000). Water scarcity and the role of storage in development. Colombo, Sri Lanka. International Water Management Institute. 27p. (IWMI Research Report 39).
- Lundqvist, J., de Fraiture, C., and Molden, D. (2008). Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain. SIWI Policy Brief. SIWI, 2008. [www.sivi.org/documents/Resources/Policy\\_Briefs/PB\\_From\\_Filed\\_to\\_Fork\\_2008.pdf](http://www.sivi.org/documents/Resources/Policy_Briefs/PB_From_Filed_to_Fork_2008.pdf)
- McCartney, M., and Smakhtin, V. (2010). Water storage in an era of climate change: Addressing the challenge of increasing rainfall variability. IWMI Blue Paper.
- Mejia, A. (2010). Water Scarcity in Latin America and the Caribbean Myths and Reality. Paper written for the Consultant Water For The Americas: Challenges & Opportunities Forum in Buenos Aires, Republic of Argentina. 15 -17November.
- Meinzen-Dick, R., Quisumbing, A., Behrman, J., Biermayr-Jenzano, P., Wilde, V., Noordeloos, M., Ragasa, C., and Beintema, N. (2010). Engendering Agricultural Research. Discussion Paper 00973 IFPRI Washington.
- Melhem S, Morrell C and Tandon N (2009). Information and communication technologies for women's socio-economic empowerment. World Bank Group Working Paper 176.
- Mokwunye, U. (2009). Regional Review of Africa's Agricultural Research and Development. Background Paper for the Global Conference on Agricultural Research for Development, March 28-31 2010, Montpellier, France.
- Mukherji, A., Facon, T., Burke, J., de Fraiture, C., Faurès, J-M., Füleki, B., Giordano, M., Molden D., and Shah, T. (2009). Revitalizing Asia's irrigation: to sustainably meet tomorrow's food needs. International Water Management Institute. Colombo and Food and Agriculture Organization of the United Nations. Rome.
- Mukherji, A., Facon, T., Molden, D. and Chartres, C. (2010). Growing more food with less water: How can revitalizing Asia's irrigation help? Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York -Food and Agriculture Organisation Paper presented at Water: Crisis and Choices – An ADB and Partners Conference. October.
- National Water Commission of Mexico (2010). *Statistics on Water in Mexico*. 2010 edition. Coyoacán
- NRSP (2001). Just one more good rainstorm. In Research Highlights 1999-2000: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
- NRSP (2002). Droughts – just poor rainwater management? In Research Highlights 2001-2002: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
- NRSP (2002). Sustained effort can pay well. In Research Highlights 2001-2002: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
- NRSP (2003). Building social capital – improving participation in NR management. In Research Highlights 2002-2003: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
-

- NRSP (2006). Creating a community of champions. In Research Highlights 2004-2006: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
- NRSP (2006). Why is youth so invisible? In Research Highlights 2004-2006: DFID Natural Systems Research Programme. UK. <http://www.nrsp.org.uk/2.aspx>
- Oliviera, AS., Trezza, R., Holzapfel, E., Lorite, I., and Paz, VPS. (2009). Irrigation water management in Latin America Chilean Journal of Agricultural Research. 69: 7-16.
- Pandit, JA., Sirotin, N., Tittle, R., Onjolo, E., Bukusi, EA. and Cohen, CR. (2010). Shamba Maisha: A pilot study assessing impacts of a micro-irrigation intervention on the health and economic wellbeing of HIV patients. *BMC Public Health.*, 10:245.
- Parry, M., Rosenzweig, C. and Livermore, M. (2005). Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society B: Biological Sciences.* 360: 2125-2138.
- Pittock, J., Meng, J., Geiger, M. and Chapagain, M. (2009). Interbasin water transfers and water scarcity in a changing world. WWF. UK.
- Postel, S. (2010). Adapting to a new normal: In The post carbon reader: Managing the 21st century's sustainability crises. Editors Richard Heinberg and Daniel Lerch. Healdsburg, CA: Watershed Media.
- Question box (2010). <http://questionbox.org>
- Rauch, T. (2009). The new rurality – its implications for a new pro-poor agricultural water strategy. InnoWat. IFAD Rome.
- Ringler, C., Rosegrant, M., Paisner, M. (2000). Irrigation and water resources in Latin America and the Caribbean; Challenges and strategies. EPTD discussion paper 64. Washington.
- Rockstrom, J., and Falkenmark, M. (2000). Semi-arid crop production from a hydrological perspective: gap between potential and actual yields. *Critical Review in Plant Sciences.* 19:319–346.
- Scanlon, B., Jolly, I., Sophocleous, M., Zhang, L. (2006). Global impacts of conversion from natural to agricultural ecosystems on water resources: Quantity versus quality. *Water Resources Research.* 43: W03437.
- Schmidhuber, J., and Tubiello, FN. (2007). Global food security under climate change. *Proceedings of the National Academy of Science.* 104: 19703-19708.
- Smets, S. (2009). Face-2-Face workshop: Regional consultations West Asia and North Africa region. Background Paper for the Global Conference on Agricultural Research for Development, March 28-31 2010, Montpellier, France.
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., and Sirotenko, O. (2007). Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, United States.
- Regional Conference for Latin America and the Caribbean, LARC (2010). 31st Regional conference for Latin America and the Caribbean, Panama City April. LARC/10/8. <http://www.fao.org/docrep/meeting/018/k7808E.pdf>
- Snell M (2001). Appropriate water lifting technologies in West Africa – a preliminary study. FAO, IPTRID.
- Svendsen, M., Ewing, M. and Msangi, S. (2009). Measuring irrigation performance in Africa. IFPRI Discussion Paper 00894.
- Tardieu, H., Onimus, F., and Mulenga, B. (2009). Profitable smallholder irrigation in Zambia: Is this a contradiction in terms? PPIAF Gridlines (in press).
- Thenkabail, PS., Biradar, CM., Noojipady, P., Dheeravath, V., Li, Y.J., Velpuri, M., Reddy, GPO., Cai, XL., Gumma, M., Turrall, H., Vithanage, J., Schull, M., and Dutta, R. (2008). A Global Irrigated Area Map (GIAM): Using Remote Sensing at the End of the Last Millennium. International Water Management Institute. 63.
-

- UNCTAD (2010). *Trade and Environment Review 2009/10: Promoting Poles of Clean Growth to Foster the Transition to a More Sustainable Economy*. New York and Geneva: United Nations.
- UNCTAD (2011). Assuring food security in developing countries under the challenges of climate change: key trade and development issues of a fundamental transformation of agriculture. Discussion paper 201.
- Upadhyay B, Samad M, Giordano M (2005). Livelihoods and gender roles in drip-irrigation technology: A case of Nepal. Working Paper 87. Colombo, Sri Lanka: International Water Management Institute.
- Van Aalst, M., Hellmuth, M. and Ponzi, D. (2007). Come Rain or Shine: Integrating Climate Risk Management into African Development. African Development Bank, Working Paper 89. Tunis.
- Van Bentum, R., and Smout, I.K. (1994). *Buried pipelines for surface irrigation*. Intermediate Technology Publications UK. ISBN 1 85339 187 5.
- Van Koppen, B. (2002). *A Gender Performance Indicator for Irrigation: Concepts, tools, and applications*. Research Report 59. International Water Management Institute, Colombo, Sri Lanka.
- Wallace, JS. (2000). Increasing agricultural water use efficiency to meet future food production. *Agriculture Ecosystem & Environment*. 82:105–119.
- Wheeler, T. and Kay, M. (2011). Food crop production, water and climate change in the developing world. *Outlook on Agriculture*. Vol 39, No4 pp 239-244.
- Winrock International. Linking Smallholders to Market Opportunities.  
<http://www.winrock.org/fact/facts.asp?CC=5463&bu=>
- World Bank (2002). Handbook on smallholder irrigation. Unpublished.
- World Bank (2006a). United Republic of Tanzania: Improving Water Security for Sustaining Livelihoods and Growth. Report No. 35327- TZ. Water and Urban Unit 1, Africa Region, World Bank, Washington, DC.
- World Bank (2006b). Ethiopia: Managing Water Resources to Maximize Suitable Growth. Agriculture and Rural Development Department, World Bank, Washington, DC.
- World Bank/IBRD (2007). Making the most of scarcity: Accountability for better water management results in the Middle East and North Africa. Washington. UN-Water (2006) Water – a shared responsibility. The United Nations World Water Development Report 2.
- World Bank (2009). Addressing China's Water Scarcity: Recommendations for Selected Water Resource Management Issues. Washington, D.C.
- World Resources Institute (2003). WRI Annual Report 2003. Washington, DC.
-





