IRRIGATION AND DRAINAGE
Irrig. and Drain. **60**: 348–359 (2011)
Published online 11 September 2010 in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.584

WATER MANAGEMENT TO MEET PRESENT AND FUTURE FOOD DEMAND†

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ABSTRACT

The emerging and least developed countries are expected to absorb virtually all the increase in the world's population. With fast-growing population and ongoing urbanization, population density with reference to cultivated land is increasing significantly. In the emerging countries the increasing standard of living and to a certain extent biofuel production are adding more pressure on the already stressed land and water resources. Currently, most hungry people live in these countries and their number has been increasing for a few years.

The least developed countries especially are regular food aid recipients. The future outlook is not promising: 80–90% of the required increase in food production will need to come from existing cultivated land. However, at present only 22% of the cultivated land in emerging and 11% in the least developed countries have irrigation facilities. Drainage development is almost non-existent.

Better use of already cultivated land and water resources to ensure the required food production can be the key. The role of effective water management thus is crucial to achieve the objective of food security. This paper substantiates that the improvements in agricultural water management are closely linked to global food production. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: emerging countries; least developed countries; arable land; biofuel; standard of living; hunger; food production; water management

Received 11 December 2008; Revised 29 January 2010; Accepted 7 March 2010

RÉSUMÉ

L'augmentation de la population mondiale se fera principalement dans les pays émergents ainsi que dans les pays les plus pauvres. L'accroissement de la population et celui l'urbanisation afférente font que la densité de population augmente aux endroits même où les terre agricoles disparaissent. Dans les pays émergents la production de biocarburants et l'augmentation du niveau de vie ajoutent à la pression foncière et sont à l'origine de tensions croissantes sur la ressource en eau. Actuellement, la plupart des personnes qui ont faim vivent dans ces pays et leur nombre a recommencé à augmenter depuis quelques années.

Egalement les pays les moins avancés sont régulièrement les bénéficiaires de l'aide alimentaire. L'avenir n'est pas prometteur : 80 à 90% de l'augmentation de la production alimentaire devra provenir des terres cultivées existantes. Or, à l'heure actuelle, seulement 22% des terres cultivées dans les pays émergents et 11% dans les pays les moins avancés sont équipées en irrigation, alors que le drainage y est presque inexistant.

Un meilleur usage des terres disponibles et des ressources en eau est au centre de la problématique de la production alimentaire, et, donc, gérer l'eau est crucial pour atteindre l'objectif de sécurité alimentaire. Ce document justifie que les améliorations dans la gestion de l'eau agricole sont étroitement liées à la production alimentaire mondiale. Copyright © 2010 John Wiley & Sons, Ltd.

MOTS CLÉS: pays émergents; les pays les moins avancés; terres arables; niveau de vie; famine; gestion de l'eau

INTRODUCTION

Population growth, environmental consciousness, urbanization, economic development and geopolitics are some of the crucial influencing factors in the present world (Global

* Correspondence to: Birendra K.C., Ministry of Local Development, Rural Community Infrastructure Works Programme, Shree Mahal, Pulchowk, Lalitpur, Nepal. E-mail: birendrakc25@gmail.com
†Gérer l'eau est indispensable pour répondre aux besoins présents et futurs de la demande alimentaire.

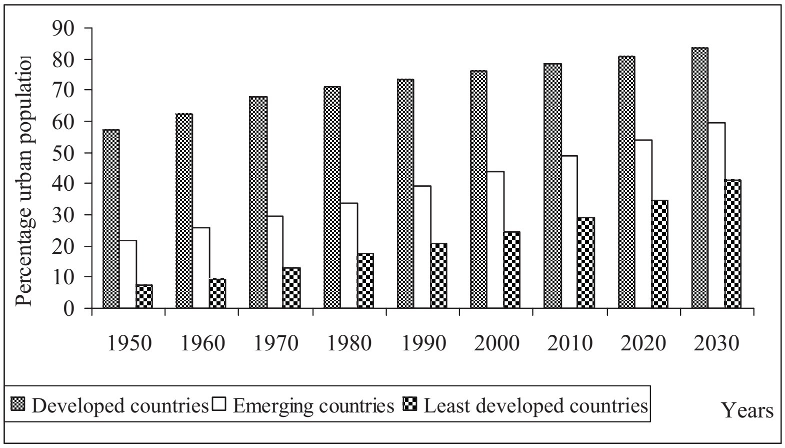

Figure 1. Development of the ratio of the rural and urban population in the different types of countries

issues on the UN agenda, 2008; Global Education, 2008; Global Issue, 2008). Moreover, population growth is significantly pressing. World population was 6.7 billion in 2007 and it is expected to reach to 9.2 billion by 2050 (United Nations Department of Economic and Social Affairs, 2008a). Virtually all this increase will occur in the emerging and least developed countries where between 2000 and 2030 the net increment in the proportion of urban population is expected to be respectively 40 and 33%[1] (Lupien, 1999; Schultz *et al.*, 2005). Urbanization is another important factor that occurs in conjunction with the population growth. Globally, the proportion of urban population was 49% (3.2 billion) in 2005 and it is expected to reach 60% (4.9 billion) by 2030 (Figure 1) (United Nations Department of Economic and Social Affairs, 2008b; K.C., 2008; Schultz *et al.*, 2009).

Most of the 2.5 billion people expected to be added to the world population between 2007 and 2050 are going to live in the cities of the emerging and least developed countries. As urban earnings are generally higher than in rural areas, urbanization is also likely to encourage a shift in people's food habits, i.e. from a more cereals, rice and wheat-based diet to more meat-oriented diet, which would require more water (Hofwegen and Svendsen, 2000). According to the Comprehensive Assessment of Water Management in Agriculture (2007), about 25% of the increasing food demand by 2050 will be due to changing food habits.

Further, in recent years, a certain number of farmers are being attracted towards biofuel production, transforming a part of the food-producing lands into non-food-producing lands (International Commission on Irrigation and Drainage (ICID), 2008a). These demographic changes and socio-economic developments result in increased competition for fresh water and agricultural land, leading to a situation of reduced per capita availability of land and water resources combined with the need for increased food production (Schultz *et al.*, 2009). The emerging and least developed countries particularly may face enormous pressures, where between 2007 and 2050 per capita available renewal water would reduce by 23% and 54% respectively (Pacific Institute, 2008). Similarly, increasing population and decreasing arable land between 2025 and 2050 are expected to result in substantial increases in population density with respect to arable and permanent crop area (APC) in the emerging countries (30%) and in the least developed countries (117%) (Food and Agriculture Organization of the United Nations (FAO, 1997); K.C., 2008).

Hence, compressing land and water resources and expanding world population are posing special challenges to increase current land and water productivity to cope with the rising food demand (Schultz *et al.*, 2007). Current land and water management practices in the emerging countries and especially in the least developed countries may be quite poor, with food production per unit of arable land and irrigation water supply substantially below the potential (Raju and Kumar, 1999). Research by the International Institute for Applied Systems Analysis (IIASA) (2009) concluded that the growth of biofuel production has exacerbated the food unavailability situation for humans, diverting agricultural land, water and other resources away from food and feed crops. This may have contributed to the increased food prices, and undernourished populations at global level from 854 million in 2006 to 923 million by 2007

[1]Most global-level studies have been based on developed and developing country groups. The latter group comprises countries with varied socio-economic conditions; from countries with rapid economic growth, such as China and India, to the much contrasting cases of Sudan and Ethiopia. By grouping them together in one, the vast differences within those countries tend to get subverted, resulting in misleading interpretations. Hence, based on the internationally accepted terminology, this study has divided the developing country group into two subgroups of emerging and least developed countries.

(FAO, 2008a). With no measures taken in time, the first objective of the Millennium Development Goals (MDG) of halving world hunger by 2015 might not come true.

This calls for a review of the food value chain, like resource management, technology, production, institution, financing, marketing (trading) and environment (Ghazalli, 2006). By addressing these issues, focusing on the main shortcomings and taking the necessary action, the situation of food security can be improved. Some drawbacks in irrigation water management that need to be improved are poor scheme management, deferred operation and maintenance, unreliable water supply and poor technical performance (FAO, 1996). In many cases, water is proportionally distributed inside the tertiary unit, which is not amenable to changing demand. So in the case of water shortages, there is a possibility of crop failure in the entire command area.

To a certain extent in the emerging countries and especially in the least developed countries existing water users' associations are generally institutionally as well as professionally weak. Options of water charging are generally focused on meeting partial or full operation and maintenance (O&M) cost whereas annual collections are often substantially below the target (World Bank, 2005b). In some schemes, fee collection rates are near zero, even when water charges are well below the cost of O&M (Easter, 1993; Svendsen *et al.*, 1997; Government of People's Republic of Bangladesh, 2000; Ahmad, 2002). Hence, annual O&M activities are deferred, impeding effective water management and retarding food production. As a result certain irrigation and drainage schemes may not even be sustainable over the long run.

So, technological development, institutional improvement, farmers' capacity enhancement along with application of adequate pesticides and fertilizers are primary initiatives in the field of irrigation to increase food production (Trewavas, 2001). Without pesticides, 70% of the world food crop would be lost (Pimentel, 1997). Application of fertilizers can increase yields anywhere from one and a half to twofold (Smil, 2000). Adoption of healthy seed of improved high-yielding varieties, well fitted to local agro-ecological conditions, could be another option to amplify production (FAO, 1999). In the same vein, to explore the options and constraints, this paper analyses various alternatives of water management of the irrigated area in the emerging and least developed countries to amplify food production and thereby help meet future food demand.

STUDY DESCRIPTION

This study is based on secondary data obtained from different information sources and literature. Apart from these, existing databases of FAO (FAOSTAT and AQUASTAT), the International Water Management Institute (IWMI), ICID, the World Bank, International Monetary Fund (IMF), and World Fact Books were also used. As the challenges are in the emerging and least developed countries only these countries are considered in this study.

All together 49 countries, comprising 33 from Africa, 10 from Asia, 5 from Oceania and the Pacific Region and one from Central and South America are in the group of least developed countries (Wikipedia, 2007); 144 countries comprising 33 from Asia, 23 from Africa, 24 from Europe, 47 from the Americas and 17 from Oceania are grouped as the emerging countries.

Review of some influencing issues related to land and water resources was done at global level, focusing on country groups in various continents. The study also involved the following:

- review of demographic factors like population growth and urban migration;
- assessment of total arable and permanent crop (APC) and per capita land;
- estimation of current production (cereal) per unit of APC land;
- appraisal of scenarios of irrigation and drainage development;
- ascertaining total undernourished population.

To relate outputs from a system to the inputs into that system a set of nine external indicators were originally presented by Perry (1996). Later, these were widely field-tested and slightly amended and published as IWMI's set of comparative indicators (Molden *et al.*, 1998), which were used to assess irrigation water management scenarios in this study. Irrigation technologies and water control structures along with organizational, financial and operational indicators were considered in order to identify the main shortcomings in prevailing practices of irrigation water management.

FINDINGS

Total arable and permanent cropland (agricultural land) in 2007 was 1.5 billion ha, which is about 11% of the global land surface of 13.6 billion ha (FAO, 2007). The distribution of land and population are 24, 66 and 10%, and 15, 73 and 12% respectively in the developed, emerging and least developed countries. Similarly the distribution of world's renewal water resources (56 billion m^3 yr^{-1}) is 18, 70 and 13% in the respective country groups. These figures reflect that the distribution of land and water resources and population are more or less consistent in the country groups. With these resources there is an export surplus of cereals of on average 10% for the developed countries, while the emerging and least developed countries have to import respectively 5 and 30% of their annual cereal consumption.

About 42% of the total population in the emerging and 62% in the least developed countries depend on agriculture, but a significant number of the rural people in these countries are in a vicious cycle of food scarcity and poverty. This implies that to a certain extent the emerging countries and especially the least developed ones have so far not been sufficiently successful to exploit the potential from the available resources. Based on population and cereal production of 2005, the analysis also shows that there is no food shortage at country group levels when compared with the basic requirement of 0.16 t yr^{-1} per person (Figure 2).

At global level, per capita food availability is 0.34 t yr^{-1} per person (calorific value 3360 kcal day^{-1} per person), which is more than the threshold of 2800 kcal day^{-1} per person. The FAO figures indicate that in 2008 total cereal consumption excluding biofuels was 2030 million t. On a worldwide basis, roughly one-third of the cereals were used for feeding livestock (Vasal, 2008). In addition about 124 million t of cereals were produced for biofuel (Alexandratos, 2008).

Impacts of biofuel production are noticeable in emerging countries like China, India, Brazil, Malaysia, Thailand, etc. For example, China is currently producing about 1.4 million t of bioethanol using maize, with a target of 10 million t in 2020 (Huge *et al.*, 2009). Brazil used some 50% of its sugar production for making ethanol in 2008 (Alexandratos, 2008) and will be expanding production of biodiesel to 5% by 2013 from 2% in 2008. Hence, if all national policies and plans on biofuels were implemented, an additional 30 million ha of cropland along with 180 km^3 of additional irrigation water withdrawal would be needed (Schultz *et al.*, 2007). Rosegrant (2008) estimated that the increased biofuel demand in 2008 accounted for 30% of the average price rise of cereals and for 39% of that of maize.

According to ICID (2008a), to feed close to 1 billion undernourished people and to address the likely dietary changes along with population increase, food production would have to double within 25–30 years. At a global level both irrigated and rainfed areas have sufficient potential to produce this food requirement by improving current land and water management practices (Comprehensive Assessment of Water Management in Agriculture, 2007). About 10 000 billion–14 000 billion m^3 of water would be needed to produce the food requirements of 2050.In comparison, at present roughly 7100 billion m^3 is required annually for global food production (considering only evapotranspiration of crops and pasture), of which 1800 billion m^3 comes from irrigation, and the remainder from rainfall (Schultz *et al.*, 2007).

However, actual water and food requirements will depend on several factors like population growth, dietary change and water management strategies. A rough estimation shows that improving water productivity by 40% on rainfed and irrigated lands could reduce the need for additional water for irrigation to zero over the next 25 years (Molden and Fraiture, 2004). This reflects how important are effective water management, selection of better varieties of seeds, and use of fertilizer and pesticides. To a certain extent in the emerging countries and more significantly in the least developed countries the performance of many irrigation and drainage schemes is significantly below their potential (Raju and Kumar, 1999; Malano and Hofwegen, 2006). During 1982–1993, the irrigated area increased by 1.5% yr^{-1}, while between 1995 and 2020 it is expected to increase only by 0.6% yr^{-1} (Pinstrups-Andersen *et al.*, 1997). This implies that though irrigation is essential for food security, the pace

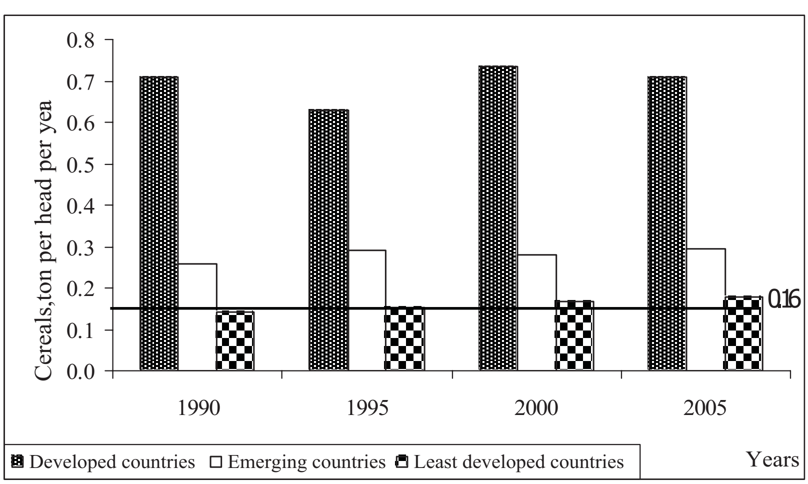

Figure 2. Cereals per person in the country groups from 1990 to 2005 (United Nations Department of Economic and Social Affairs, 2008b; FAO, 2007a)

Table I. Irrigation and drainage development in the country groups in 2007

Country group	Total irrigated area	Total drained area	Rainfed drained area	Total area with a system	Irrigated and drained area	Irrigated area without drainage
	(Mha)	(Mha)	(Mha)	(Mha)	(Mha)	(Mha)
Developed countries	43	103	54	97	9	35
Emerging countries	220	96	25	246	43	177
Least developed countries	17	4	1	18	0	17
Total	281	203	80	361	52	229

Sources: *FAO Statistical Year Book, 2005–2006*; FAO-AQUASTAT with University Frankfurt (2007); International Commission on Irrigation and Drainage (ICID) (2007); CEMAGREF (2007).

of irrigation development has so far been at too low a level. Fortunately recently a substantial increase may be observed. Still, almost 76% of the total arable and permanent cropland in the emerging and 88% in the least developed countries lack both irrigation and drainage facilities (Table I).

One of the limitations in the field of agricultural development that is impeding effective water management is irrigation supply technology. In many irrigation schemes like the Sunsari Morang Irrigation Scheme in Nepal and the Sri Ram Sagar Irrigation Scheme in India, water is proportionally distributed inside the tertiary units. It is the easiest way to allocate water but it cannot address changing demand and supply. This type of irrigation supply is applicable only if water availability in the scheme is sufficient. Otherwise, in water-scarce situations, it will create water stress in the entire command area. In some schemes, like the Yaqui Irrigation District in Mexico, rotational water distribution is practised where because of adjustable water control structures it is possible to maintain flexible irrigation supplies. In many irrigation schemes water distribution is not uniform, for example in the Sunsari Morang and Sri Ram Sagar Irrigation Schemes where downstream farmers are always voicing their dissatisfaction. The main reason behind this is the unclear water use right and its poor implementation. In schemes like Yaqui Irrigation District, both provision of the water use right and its implementation are excellent, which has resulted in uniformity in irrigation supply. In addition, a tradable water use right in such schemes gives an opportunity to users to buy water from nearby farmers which increases reliability. Consequently, productivities in such schemes are higher.

Jointly managed irrigation schemes and farmer-managed irrigation schemes exist mostly in the emerging and least developed countries. In jointly managed irrigation schemes concerned agencies are responsible for O&M of the scheme up to secondary level, and below that it is the respective water users' associations (WUAs). In farmer-managed irrigation schemes, the WUAs are responsible for the O&M of the whole scheme.

Broadly, two types of WUAs are in existence: socially oriented and business oriented. In socially oriented WUAs, governments work with farmers to run the scheme and WUAs are generally not allowed to hire any staff., while in business-oriented associations, the WUA hires professional staff to undertake management activities. Although, in general, WUAs fix and collect the annual irrigation service fee (ISF), comparatively collections are far better in farmer-managed irrigation schemes. For example, in the Sunsari Morang Irrigation Scheme the annual fee collection is hardly 12% against the target while in Yaqui Irrigation District (farmer-managed irrigation schemes) it is 100% (K.C., 2008). Further, in jointly managed irrigation schemes, even if the targeted ISF is fully collected it often does not cover the whole annual O&M cost of the scheme. However, in farmer-managed irrigation schemes, the targeted fees generally fully cover the O&M expenses.

Therefore, in jointly managed irrigation schemes annual required maintenance tasks may be deferred. For example in the Sunsari Morang Irrigation Scheme the silt load in the canal system was recorded as 354 000 m^3 in 2002/2003, which was more than threefold the previous year. If the situation is not resolved it may severely undermine the system's performance. Another problem in jointly managed irrigation schemes relates to sharing of collected ISF between the government and farmers. As generally almost 50% of the collected ISF goes to the government treasury, farmers are not willing to pay, because they are not sure whether this money would ever come back to their scheme. In farmer-managed irrigation schemes all collected ISF generally remains with the WUAs. In many studies, land and water management practices and consequently food production per unit area and irrigation supply are found to be better in farmer-managed irrigation schemes in comparison to agency managed (FAO, 2000; Bhatta *et al.*, 2005; K.C., 2008).

COMPARATIVE DISCUSSION

Increasing demands for food with limited land and water resources call for improved agricultural planning and execution. Effective water management is central to this, because it has a direct influence on food production and the livelihood of farmers.

Scope for productivity improvement on the existing cultivated land is higher than agricultural area expansion

As mentioned earlier, raising production can be done by increasing arable land and/or by raising the productivity of the cultivated area. However, the potential for expansion of arable land is limited. Hence, productivity of the currently used land needs to be increased. Further, the land which is currently in use also has very promising potential for improving productivity, which is yet to be exploited (Trewavas, 2001). This implies that improvement in land and water management of the existing agricultural area is a prerequisite for expansion of current food production. Therefore it is essential that in the coming decades about 80–90% of the required increase in food production be realized on existing cultivated land and about 10–20% on newly reclaimed land (Hofwegen and Svendsen, 2000; FAO, 2006).

Focus on rainfed or irrigated agriculture depends on socio-economic and climatic conditions

The majority of the world's poor live in rural areas and depend on rainfed agriculture for food, income and thus livelihood. They play an important role in economic development and poverty reduction (Irz and Roe, 2000; World Bank, 2005a). For example in sub-Saharan Africa, which includes most of the least developed countries, agriculture accounts for 35% of the gross domestic product (GDP) and employs 70% of the population (World Bank, 2000). More than 95% of the agricultural area is rainfed (FAOSTAT, 2005). Insecure and unreliable access to water for consumption and productive uses is a major constraint on poverty reduction (FAO, 2008a). Hence, for millions of poor farmers, access, control and management of water, availability of improved varieties of seeds, as well as appropriate fertilizers and pesticides, are vital to increase food production and raise their living standards.

At the global level there are areas with greater possibilities of improving rainfed agriculture than irrigated cultivation. For example, in addition to sub-Saharan Africa, Latin America with mostly emerging countries, shows a higher scope for improved productivity in rainfed areas than in irrigated areas (Comprehensive Assessment of Water Management in Agriculture, 2007). Similarly, the Middle East and North Africa have comparable possibilities of improving productivity in rainfed and irrigated areas.

Today about 45% of total food production comes from rainfed agriculture without a drainage system, which covers nearly 77% of the world's harvested cropland. But at the global level rainfed agriculture has sufficient potential to produce enough food to meet present and future demand by improving land and water management practices. Relying on minimal increases in irrigated agriculture and by reaching 80% of the maximum obtainable yield in rainfed agriculture, only a 7% increase in total cropland would be required to produce the food required by 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007).

There is a strong link between irrigation, poverty alleviation and food security (United Nations World Water Development, 2006). Food production by improving irrigation and drainage schemes has a hugely positive impact on society. It creates direct job opportunities and indirect jobs in areas that are linked with agricultural businesses. Besides employment generation and food security, irrigated agriculture may also contribute to social harmony. Thus, in general irrigation improves the well-being of the rural poor (Van Koppen, 1998). In a broad sense, productivity enhancement by improving irrigation and drainage schemes means deriving more benefits and helping alleviate poverty.

Therefore, increasing productivity of the irrigated area, which needs comparatively less water and gives higher productivity, along with improving farmers' accessibility to and affordability of available food, could be an option to address the problem of food scarcity. However, productivity improvement of rainfed or irrigated areas mostly depends on the climatic conditions and water availability in the region. In desert and arid areas, irrigation is absolutely essential for crop growth. Even in semi-arid areas, irrigation is indispensable for a reliable and good harvest. Some drought-resistant crops such as sorghum and millet may give reasonable yields, but there is always a risk of crop failure due to unreliable rainfall. Agriculture is normally impossible without a supplementary irrigation system. In humid tropical areas, a distinction is made in cultivation during the wet and the dry monsoon. Irrigation is generally required only during the dry season. Wet monsoon cultivation is generally possible with a just a drainage system, although quite often irrigation is applied to overcome dry spells. In temperate humid areas, irrigation is not usually required. During more than nine months of the year there is excess rainfall, and even in the remaining drier months the plants may use water stored in the root zone during the rainy season. Drainage systems are used for salinity control and preventing areas from possibly becoming waterlogged.

Production increase in rainfed areas would have to be achieved by improving water management through measures like water harvesting and watershed management techniques that improve soil moisture conditions, reducing non-beneficial evaporation from bare soil through mulching and wind breaks, and installing drainage systems where necessary. Similarly, by adopting quick-growing and high-yielding crops fuelled by supplemental irrigation and agricultural inputs evapotranspiration can be reduced and production increased. Supplemental irrigation with about 100 mm of water provided during crucial drought spells can double rainfed yields from about 1 to 2 t ha^{-1} of cereals, increasing water productivity to 0.5 kg m^{-3} of water consumed (Rijsberman, 2008). In addition, agricultural extension and support will need to be provided to farmers to ensure effective water management resulting in good yields.

Productivity improvement in irrigated areas has better scope than irrigated area expansion

Since 1950 the irrigated area has doubled and water withdrawal tripled (Comprehensive Assessment of Water Management in Agriculture, 2007). But in the context of the present world, expansion of the irrigated area and increasing irrigation water supplies are not that easy, because large proportions of land and water resources are already being transferred from food-producing to the non-food-producing areas. Further, expanding the irrigated area requires relatively large investment to establish new infrastructure and might cause environmental deterioration. Hence, the capital cost for irrigation area expansion is higher per unit area in comparison to the cost required to improve productivity of the irrigated area. In addition, at global level the sub-Saharan region shows a greater scope for irrigated area expansion. Here, doubling the irrigated area would increase food contribution of the irrigated area from 5% now to an optimistic 11% by 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007).

By reducing 80% of the gap between actual and obtainable irrigated yield by improving water management on existing irrigated lands, 540 million t of grain can be ensured which is 75% of the additional global food demand by 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). In contrast, irrigated area expansion by 35% contributes only 260 million t of grain. In terms of water requirements, yield improvement would increase water diversion by 30% whereas irrigated area expansion would increase it by 55%. In South Asia, where more than 50% of the cropped area is irrigated and productivity is relatively low, additional food demand can be met by improving output per unit of water in irrigated agriculture. Therefore, productivity increments in existing irrigation and drainage schemes that are water efficient, economic and environmentally friendly, could be helpful in addressing the problems of food scarcity and poverty alleviation. To enhance the performance of irrigation and drainage schemes, a lot has to be done. Some of the issues that have to be addressed include:

- improve efficiency and water saving;
- reforms towards stakeholder-controlled management and government support;
- modernization of existing schemes;
- increased stakeholder participation;
- transfer of management responsibilities of at least parts of the schemes to the users;
- improved cost recovery, particularly for recurring O&M.

Especially in the water-scarce arid and semi-arid zones, the required increase in efficiency and water saving is a very important issue. Organizational restructuring in order to attract farmers' involvement in agricultural development is another important step. Therefore, in many countries institutional reforms in irrigation and drainage system management towards stakeholder-controlled management are ongoing (Japanese National Committee of ICID, 2000; Czech Committee of ICID, 2001; Ukraine National Committee of ICID, 2002).

Further, in order to create ownership, transfer of irrigation and drainage schemes to the stakeholders is important. It has a positive impact on land and water productivity improvements. For example, in Mexico, after the transfers in 1994, the agricultural productivity of 38 irrigation districts has substantially increased. Average land productivity increased by 39%, water productivity by 62%, and wheat productivity by 41%. At country level, the cost recovery of the irrigation schemes was continuously declining before the management transfers; afterwards the financial self-sufficiency of the irrigation districts reached 72% in 1999 from 43% in 1989.

Transfer of irrigation and drainage schemes requires quite different approaches based on the current structure of the schemes (Schultz, 2002). For example, in the emerging and least developed countries, in spite of having farmers' associations, the main responsibility for O&M originally was generally in the hands of central governments. In such cases, responsibility and ownership need to be transferred from the government to the farmers, and/or irrigation or drainage agencies. There are still some countries without farmers' associations, where the process of transfer is quite complicated. This is because, first, farmers have to be organized into their organization, and then their capacities enhanced to successfully assume the irrigation management responsibilities. This is generally a lengthy and stepwise process. In some cases, there are farmers' associations but they are not in line with the objectives of management transfer. In such cases, institutional reforms may be required before transferring irrigation or drainage system management.

Further, existing irrigation and drainage schemes need to be upgraded because significant parts of current irrigation and drainage systems are more than 30 years old. When consideration is being given to producing most of the required food from existing cultivated land, more attention needs to be paid to scheme modernization, including necessary institutional reforms, WUA strengthening and cost recovery aspects. The issue of cost recovery is more important for the sustainability of modernized systems. Responsibilities and funding options of the government, agencies and farmers as forwarded by Schultz (2003) for modernization and operation and maintenance of systems when they have been modernized are relevant (Figure 3).

Business-oriented WUAs can handle comparatively more complex schemes than socially oriented WUAs. In many emerging and least developed countries, there exists a social mode of WUAs with no provision for hiring professional staff. Such WUAs are institutionally weak and generally poorly performing. In most cases, WUAs are responsible for fixing and collecting the annual ISF, but in many schemes revenue collection is far below target. In addition, in many irrigation schemes annual ISFs are not enough even to cover the annual O&M cost. Consequently annual maintenance activities are delayed and accumulate at the cost of serviceability of the irrigation schemes.

In countries like Mexico, business-oriented WUAs exist which hire technical staff. In such schemes, annual ISF collection is generally 100% and fully covers O&M expenses. With hired skilled professionals they can perform relatively complex jobs.

Selection of proportional or rotational water distribution highly depends on water availability and farmers capacity to operate the scheme

Most of the irrigation schemes fail to meet their objectives because of the complexity of the adopted irrigation water supply technology. Hence selection of a suitable technology is an important aspect in achieving high agricultural productivity. Applicable technologies are space- specific, having a direct relation with climatic conditions and farmers' understanding.

One of the main factors contributing to poor performance in irrigation water supply is the lack of effective water control structures. A combination of sufficient and suitable control structures inside irrigation and drainage schemes is essential to facilitate operational procedures. In the same context, flexibility and reliability are prerequisites for meeting the objective of improved productivity. Flexibility is achievable by introducing adjustable control structures at different locations of the canal system, and reliability by constructing reservoirs or supplementing supplies from groundwater, where viable.

In many emerging and least developed countries, water is proportionally distributed inside the tertiary units, which cannot address changing demand and supply due to the proportional division boxes. In addition, it is hard to implement tradable water use rights with such a water distribution system. Because if one level of WUA is trading water to the next level WUA then there needs to be adjustable water control structures between them. Rotational water distribution, on the other hand, does not have such limitations. In addition, different prioritizations are possible

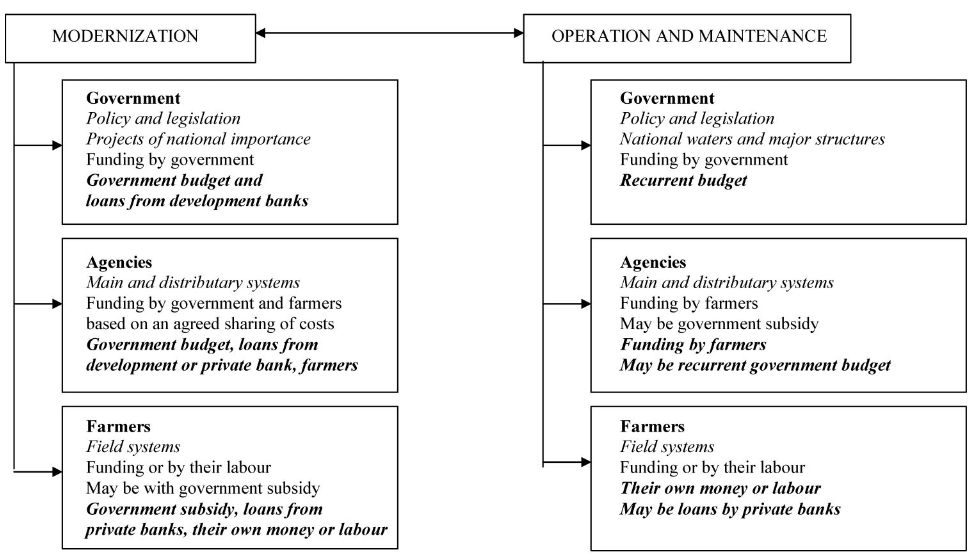

Figure 3. Responsibilities and funding options for modernization and operation and maintenance of systems when they have been modernized (Schultz, 2003)

in a rotational supply. But rotational water supply is only possible with adjustable water control structures, which are harder to operate and need a skilled workforce. In other words, rotational water supply is only possible with capable WUAs.

Cultivation of staple or high-value crops depends on multiple factors

Improvement in land and water productivity means producing more crops per unit land and irrigation water supply. Similarly, higher economic land and water productivity implies higher economic return per unit crop area and irrigation water supply, for which high-value crops are very suitable. But adoption of high-value or staple crops depends on various factors like water availability, irrigation supply technology, market access, seed and fertilizer availability and government policy.

In addition, farmers need strong motivation as it is risky in case of water scarcity. Currently many of the least developed countries are not in a position to provide subsidies or insurance to farmers. In such a case, cultivation of high-value crops may not lead to the desired results. Comparatively, emerging countries have stronger economic circumstances hence the adoption of high-value crop cultivation may be more promising.

Selection of improved crops and application of proper fertilizer lead to higher production

Development of several varieties of seeds can help make effective use of land and water resources. For example, salt-tolerant varieties can be cultivated in saline conditions. Varieties with increased tolerance of short- or medium-term water deficits will facilitate water saving and reduce the need for supplemental irrigation under rainfed conditions. Varieties tolerant to waterlogging and flooding will reduce the impact of poor drainage (Bennett, 2003).

Similarly, cultivation of improved seeds leads to increase in production as they are more drought and disease resistant. For example in Jumla in Nepal, which is the highest point in the world for rice cultivation, after adopting the improved seed Tondonnath 3, rice productivity has increased to 2 t ha^{-1} from originally 1 t ha^{-1}. In Nicaragua, productivity tripled by using improved seeds. Application of proper fertilizer is a useful strategy to enhance productivity. Use of 1 kg nitrogen can help produce 20 kg of rice. Hence, proper use of improved seeds, chemical fertilizer and irrigation water supply can contribute significantly to increase production.

CONCLUDING REMARKS

The emerging and least developed countries are showing significant population growth and urbanization. Especially for the emerging countries, an increasing standard of living and to a certain extent farmers' attraction towards biofuel production are posing a threat to agricultural land and irrigation water. The situation is worst in the least developed countries where almost 50% of the population live on less than US$1 a day. They cannot even meet their basic needs. The future outlook is also not promising. The projected number of people living in extreme poverty by 2015 is 470 million and the number of undernourished people is increasing (FAO, 2008a).

However, duplication in food production is primarily achievable by improving production per unit area of already cultivated land. Accessing more food through increased imports is technically possible because at the global level there is enough food to meet the demand. Food availability in the developed, emerging and least developed country groups is respectively 0.71, 0.29 and 0.18 t yr^{-1} per person. This makes global per capita food availability at 0.34 t yr^{-1} per person (in calorific value 3360 kcal day^{-1} per person) which is more than twice the basic requirement of 0.16 t yr^{-1} per person. This implies that hunger is largely due to inadequate distribution of available food rather than insufficient production.

This calls for improving food distribution scenarios, which depend on multiple factors and might take time. There is always the question of practicality, affordability and other institutional constraints. Hence, for the least developed countries with poor economic standing it is better to improve their own on-farm food production. About 62% of the total population depend on agriculture, and for them land and water are the most important available resources. Even for the emerging countries where about 42% of the total population depend on agriculture and show a relatively strong economy, increasing production would have to be the first priority. In some cases, a balance between production and imports could be a conceivable strategy.

For the least developed countries a small-scale stepwise development approach seems more logical than a large-scale rapid development from the socio-economic point of view. Hence, smallholder farmers in these countries would have to go for comparatively cheaper solutions, like water harvesting and watershed management techniques to improve the soil moisture conditions, mulching and wind breaks to reduce non-beneficial evaporation, micro irrigation, low-cost tubewells and improvement of the existing low-cost irrigation and drainage schemes. Similarly, adoption of quick-growing and high-yielding crops supported by supplemental irrigation and deficit agriculture practices can be a promising strategy in water-scarce areas. Emerging countries could go further with installation of new irrigation and drainage schemes where feasible, upgrading and modernization of existing schemes, creation of (large-scale) reservoirs and water transfers. Reservoirs ensure water supply for irrigation and other sectors throughout the year when there is enough water in the reservoir.

Improving institutional arrangements, organizational set-up and capacity building of farmers and irrigation agencies are some additional measures that could help improve water management. Options recommended for irrigation management include: improvement in water allocation technology based on climatic conditions and capacity of WUAs; combining sufficient and suitable flow control structures in different locations of the canal networks that support effective water control mechanisms. Where useful, construction of reservoirs is an option to facilitate reliability and flexibility and to balance supply and demand. Clearly defined tradable water use rights are also a complementing option. WUAs need to be strengthened by involving them at the relevant levels of the scheme activities, including planning, design and implementation. In addition, some capacity building training would have to be provided to the stakeholders. Similarly, farmers would have to be empowered and encouraged to engage in income-generating activities to improve their purchasing power and undertaking O&M based on the capacity of WUAs. Further, WUAs need to be legalized to enable them to collect annual ISF, and the O&M requirements would have to be covered by water service charges for the schemes to be economically sustainable. With the effective implementation of these possible measures to make efficient use of available land and water resources, meeting present and future food demand seems to be well achievable.

NOTE

1 Most global-level studies have been based on developed and developing country groups. The latter group comprises countries with varied socio-economic conditions; from countries with rapid economic growth, such as China and India, to the much contrasting cases of Sudan and Ethiopia. By grouping them together in one, the vast differences within those countries tend to get subverted, resulting in misleading interpretations. Hence, based on the internationally accepted terminology, this study has divided the developing country group into two subgroups of emerging and least developed countries.

ACKNOWLEDGEMENTS

The authors would like to thank all who directly or indirectly supported the preparation of this paper.

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