SUSTAINABLE WATER RESOURCES MANAGEMENT IN THE AGRICULTURAL SECTOR OF A DEVELOPING COUNTRY: ESSENTIAL TO ECONOMIC DEVELOPMENT

by

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Table of Contents

List of Figures

List of Tables

Abstract

Statistics show that over 3 billion people, which is more than half of the population in the developing world lived in rural areas in 2001 (Todaro, Smith, 2003). In Africa, the ratios are much higher, with most countries having rural inhabitants in excess of three quarters of the total population. Africa has the highest population growth rate in the developing world; food production in the poor countries is not keeping pace with population growth. Water is essential for production of food but the world faces serious and rising difficulties in maintaining water quality and meeting the rapidly rising demand for water resources; especially in developing countries. Furthermore, some of the water used for irrigation, which is thought to be the most important use of water in the developing world, will have to be shifted for use in industry and urban areas; wherein it should be seen as a main stimulus for agricultural development and growth.

It is arguable that the majority of the limiting factors of food production on the African continent are the quality and quantity of available water resources. This thesis aims to explore the reasons for sustainable water resources management in the agricultural sector of an economy. It will focus on general water allocation problems in agriculture, the different water management techniques and finally it will highlight on how the water needs for the agricultural sector will aid in increasing food productivity, thus, economic development in developing countries especially Africa. This thesis will cite various examples; most in the both the developing world to provide a broader perspective on water management techniques and how it is can be used towards sustainable agricultural development.

Chapter 1. Introduction

Of agricultural output, the growth in most developing countries during the past few decades has not carried much weight; as a matter of fact the share of agricultural output in total GNP has declined. Despite accounting for the majority of employment in the developing world, agriculture accounts for a much lower share of output. Often, the role of agriculture in economic development has been overlooked and at best, it has been viewed as passive and supportive. However, the historical experience of developed countries does not substantiate the notion of a marginal and passive agricultural sector. Their agricultural sector's primary role provided sufficient low-priced food and man-power; enough to permit the expansion of the manufacturing sector, which was the leading sector in their economic development (Todaro, Smith, 2003). Arthur Lewis's famous two-sector model on economic development lays great emphasis on how development can take place by means of structural transformation through rapid growth. The manufacturing sector fueled by cheap surplus labour and cheap food provided by the agricultural sector would naturally commence development. Nevertheless, water is also essential for agricultural development.

Water is one of the vital elements of life. We humans depend not only on an intake of water to replace the continual loss of body fluids, but also on food sources which themselves need water to survive. Because of the variability in rainfall, which can result in floods one year and drought in another year, the stable water supply is only about one-third to one-half of the total supply (Falkenmark, Lindh, 1974). Furthermore, the most serious water shortages during the next few years are expected mainly in the developing world; where poverty is rampant, population growth rate is very high and the need for economic development is most acute. Global numbers on the availability of water are quite misleading since water is abundant globally and it is often scare locally. All forms of agriculture production depend on water, whether for rainfed or for irrigated crops and pasture. Irrigation reduces the negative effects during seasons of low rainfall; it allows crops to be grown and stocks of food to be kept in areas where habitation would otherwise not be possible. Irrigated agriculture accounts globally for one-half to three-quarters of total water consumption, including domestic and industrial use (Postel et al., 1996).

Irrigation has played an enormous role in increasing agricultural output worldwide. However, water allocation has undergone a significant shift since the turn of the century, when almost 90% of water resources were consumed primarily by agriculture. Recent statistics (Postel et al., 1996) indicate that irrigation worldwide now accounts for 62%, whereas industrial and domestic water consumptions have increased from 6 to 25 % and from 2 to 9% of total water usage, respectively (FAO, 1993a, b). In all the developing regions, water availability per capita is lowest in Africa. Water scarcity is becoming a primary cause of slowdowns in projected irrigated cereal yield growth in developing countries. Africa has suffered the most from its inability to expand food production at a sufficient pace to keep up with its rapid population growth.

In addition, progressively more agricultural water consumption will have to compete with more lucrative utilization of water in the urban and industrial sectors; this will essentially mean that for a country to use water for other purposes aside from food, the country must be able to import food from other countries or find ways to use its available water more efficiently. Understanding how to use water more efficiently serves as the basis of this thesis. Chapter 1 examines the theoretical framework of water resources and provides an understanding to why economic efficiency is important in water management strategies. There are numerous challenges caused by the rising scarcity of water most of them experienced in developing countries. Chapter 2 covers a review of literature on water resources and economic development. This chapter offers an insight to the link between the two and points out the problems and difficulties often associated with water use in agriculture and the need for sustainability. There are two strategies applied in the management of water namely, supply management and demand management strategies. Demand-side management strategy addresses the incentives and mechanisms that promote water conservation and the efficient use of water (Rosegrant, 2000). Chapter 3 explores this concept in depth and gives examples using two distinct countries, China and Mexico.

Supply-side water management strategy, on the other hand, involves activities to locate, develop, and exploit new sources of water. Supply management strategy emerges as the focus of Chapter 4; this chapter discusses small-scale and large scale irrigation projects and describes the concerns arising from poor management practices. To get a broader perspective different countries in the developing world are citied. Chapter 5 showcases the experience from two countries; Tunisia and Nigeria. Chapter 6 uses empirical data to analyze the underlying argument of this thesis, i.e. through means of sustainable water use in agriculture, food production increases giving high incomes to farmers, which results in increased productivity and per capita income and ultimately economic development. Finally, the last chapter summarizes the thesis as a whole and pulls together concluding points.

Chapter 2. Water Resources and Its Theoretical Framework

2.1 The Potential for Water Scarcity

The earth's renewable supply of water is governed by the hydrologic cycle, a system of continuous water circulation. Colossal quantities of water are cycled each year through this system, despite the fact that only a fraction of circulated water is available each year for human use (Gleick, 1993). Of the estimated total volume of water on earth, only 2.5% (1.4 billion km^3) of the total volume is freshwater. Of this amount, only 200,000 km^3, or less than 1% of all freshwater resources (and only 0.01% of all the water on Earth), is available for human consumption and for ecosystems (Gleick, 1993). When compared to current consumption of water on a global scale, we realize that the available supply of freshwater (total runoff) is currently about 10 times larger than consumption (Tietenberg, 2005). Although subtle, this statistic shows the impact of growing demand and the rather severe scarcity situation that already exists in certain parts of the world; certainly in most developing countries. In a nutshell, water scarcity is already upon us and we can be expected to experience water scarcity in the next few decades.

Available supplies are derived from two different sources of water; they are surface water and groundwater. Surface water consists of the freshwater in rivers, lakes, and reservoirs that collects and flows on the earth's surface. In contrast, groundwater collects in porous layers of underground rock known as aquifers. Groundwater can draw down aquifer for some time, but eventually it cannot withdraw more than is naturally recharged given that most of it is accumulated over geologic time and also because of its location. Nevertheless, some groundwater is renewed by percolation of rain or melted snow. According to the UN Environment Program (2002), 90% of the world's readily available freshwater resources is groundwater. And only 2.5% of this is available on a renewable basis. The rest is a finite, depletable resource. This clearly calls for sustainable water resources management.

2.2 Water Management from an Economic Viewpoint

Water Resources Management is the integrating concept for a number of water sub-sectors such as hydropower, water supply and sanitation, irrigation and drainage, and environment. An integrated water resources perspective ensures that social, economic, environmental and technical dimensions are taken into account in the management and development of water resources. Water is set apart from most other natural resources and commodities by a number of particular characteristics that represent considerable difficulties for the design and selection of water allocation and management institutions (Young, 1986).

Water has unique characteristics which include: its hydrological and physical attributes, its pattern of demand and the social attitudes and legal/political considerations arising from its use. The hydrological and physical attributes of water deals with the fact that water is mobile, its supplies tend to be highly variable, water is nearly universal solvent, water problems are often site specific, supply facilities exhibit large economies Groundwater can draw down aquifer for some time,of size and groundwater supplies have distinctive attributes. The demand for water is mostly likely seen from a user's perspective and considers five different classes of values associated with water; they are commodity benefits, waste assimilation benefits, public and private aesthetic, recreational, and fish and wildlife habitat values, biodiversity and ecosystem preservation and social and cultural values.

Social attitudes towards water usually conflict with economic values as water is so essential to life. Because clean water and sanitation are essential to health, most people argue that market allocation mechanism should be rejected in favour of regulatory systems; this was the basis for one of the guiding principles of the Dublin Conference on Water and Environment in 1992. It states that "…..it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price" (UN 1992). Legal and political concerns mainly deals with the issues of transactions costs given the relative scarcity of water and the cumulative impact of many small decisions as the sum total of many individual decisions could carry weight. Both concerns are of major importance as water is known to be a "common pool" resource as it reflects rivalry and high exclusion costs. By rivalry we mean, if a unit of water is consumed by one individual, then it must mean that it is not fully available to other potential users. By high exclusion costs we mean that the costs to a government or private body associated with excluding potential unentitled users from taking advantage of the water resource would be high.

These distinguishing characteristics explain why water is for the most part a good not traded on regular markets i.e. why nonpriced side effects regularly accompany water use, and why artificial estimates or shadow prices are important for water allocation and investment decisions. Water management policies can affect vast variations in the quantity of available water, its quality, and the timing and location its supply. The increasing scarcity of water and growing competition among water users calls for the development of rules that promote its efficient use. Clear and practical rules have viable meaning in resolving conflicts.

2.3 The Need for Economic Efficiency in the Management of Water

Economic efficiency is defined as an allocation of resources such that no further reallocation is possible which would provide gains in production or consumer satisfaction to some firms or individuals without simultaneously imposing losses on others (Young, 2005). This definition of economic efficiency, called Pareto optimality, is satisfied in a perfectly competitive economy. A perfectly competitive economy without externalities or indivisibility is efficient in this sense. A salient characteristic of economic efficiency is that the marginal benefit of using a good or service is equal to the marginal cost of supplying it.

It must be pointed out at this stage that water demand management policies such as pricing strategies are still largely under utilized in many parts of the developing world as opposed to water supply management, which will be discussed in later chapters. A growing tendency in the irrigation sector around the world stresses pricing and charging for water as an important means of regulation. For instance, the European Union's Water Framework Directive of 2000 calls for full cost recovery in all sectors to reflect the true expense of using water (Kallis and Butler, 2001). In most cases in the developing countries, however, one of the conditions for financing irrigation projects by international development agencies require that appropriate pricing of the irrigation water be made known. What exactly these appropriate and true water prices are and how they should be applied is unfortunately lacking clarity.

Implementation costs play a major role in the achievement of efficiency as efficiency relates to the maximization that can be generated from irrigation water but it generally is silent about the way this total benefit is distributed among water users; distributional considerations have to be included in a water pricing scheme. Over time and across geographical regions, a variety of water pricing methods have evolved, which include methods based on the volume of water used "volumetric", on output or other inputs, on the size of the irrigated or cultivated area, as well as on different forms of water markets (Dinar and Subramanian, 1998). These methods all differ in the way they are carried out, the institutions they require and the information on which they are based. They also differ in the performance of their outcomes wise and their implementation costs (Tsur and Dinar, 1997).

2.4 Water Allocation Decisions

Farm-level water allocation decisions deals with the interaction of economic and environmental variables in determining the choice of irrigation technologies and the rate of water use. In a farm level model, the distinction between effective water and applied water gives rise to the concept of water efficiency. Effective water means the water that is actually utilized by the crop and is commonly measured by crop evapotranspiration[1] coefficients (ET) (Stewart et al., 1974; Grimm et al., 1987). Water efficiency is highly dependent on the ability of the soil to store water which can be utilized by the crop over time (Zilberman, 1985). Normally, water efficiency is much higher on heavier clay soils

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[1] Evapotranspiration (ET) is the sum of evaporation and plant transpiration; it is a significant water loss from a watershed.

which retain applied water rather than with sandy soils through which water passes rapidly.

Moreover, climate and water quality also affect water efficiency. These factors, through their effect on water efficiency are known to influence irrigation technology choices (Boggess et al., 1993). A simple model by David Zilberman was developed to illustrate how land quality and effective water influence farmers' choice of irrigation technology and water use. Even though the model is beyond the scope of this thesis, it has important implications to take into consideration as it deals with modern technology versus traditional technology adoption for irrigation. The model concluded that modern technology will be preferred in cases where the increased profits from higher yields or lower water costs offset the higher costs associated with adoption of the technology. Therefore, modern technology adoption will increase when there is increasing water or output prices. Also, modern technology adoption is more likely to occur with poor land quality, due to the high price of effective water under the traditional technology, and the land-augmenting qualities of the modern technology as under most conditions; modern technology adoption results in both a decrease in overall water use and an increase in crop yields (Zilberman, 1985).

Irrigation water that is not used by crops is a major source of pollution, as it may result in water-logging and salinization[2], which injuries and may eventually prevent agricultural production. Zilberman's model was further extended to reflect how the choice of irrigation technology can also affect the creation of negative environmental

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[2] Water logging is defined as the saturation of soil with water. This occurs (as is common for salinization) in poorly drained soils where water can't penetrate deeply. For example, there may be an impermeable clay layer below the soil. It occurs on areas that are poorly drained topographically.

externalities in the form of agricultural drainage water. Again, Zilberman concluded that modern technology adoption will be the better choice as subsidizing modern irrigation technology will increase the quasi-rent associated with its adoption, leading to higher adoption rates and lower amounts of agricultural drainage.

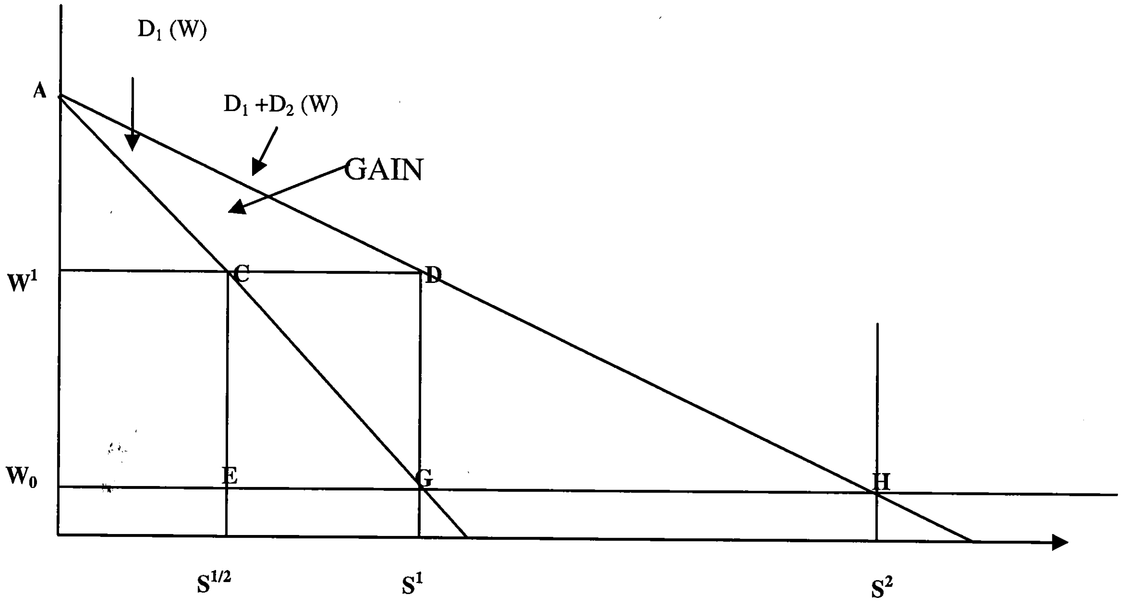
The emphasis in water economics research has shifted from the expansion of new sources of water towards improving the efficiency of existing uses. Surface water allocation mechanisms deal with water rights regimes that decide upon the allocation of surface water and, in some cases, ground water. There are two main types of water rights generally speaking; they are riparian and prior appropriation. The riparian system allows individuals bordering a body of water to share the water, but prohibits diversion of the water to areas further from the source. Whereas with the prior appropriation system, the rights of users are queued according to the time at which they first start diverting water. In other words, users are allowed to divert water for "beneficial" uses; however, they are not allowed to sell it (Cuzan, 1983; Gardner, 1983).

These water right systems were originally established under historical conditions when there was belief that abundant water supplies existed. However, under current conditions of increased scarcity of water supplies, these systems may very well result in inefficient water allocation as they result in senior rights holders being able to divert water for low productivity uses; which hinders higher productivity uses among junior users. Efficiency would rather be obtained if low productivity water could be transferred from senior to junior rights holders resulting in greater productivity. Market systems for the allocation of water resources may be a more efficient means but it must be stressed that it is only under certain market systems that results are largely favourable as we would see instances of these in following chapters.

The several characteristics of water resources which include, high transactions costs in trading, third party impacts, non-excludability of certain water use benefits, natural monopoly conditions and equity issues, may hamper the introduction of markets. A simple framework again by David Zilberman is used here for analyzing the welfare implications of a move from queuing to a market system. Using the Burness and Quirk's (1979) framework, we will analyze resource allocation under the prior appropriation system to show the welfare implications of the introduction of markets.

Let i identify water uses, with i = 1 for most senior user and increasing for more junior users. Let Di (.) be user i's demand for water, and assume that the per unit cost of diverting water is W_0. The figure below depicts the case of two users with identical demand curves, where $D_1(W)$ is the demand of the senior rights owner and $D_1(W) + D_2(W)$ is the aggregate demand of the two. We assume there are two states of water supply: low and high. S^1 in the figure below denotes water supply in the low state and is equal to the quantity demanded by senior rights owners at $W=W_0$ and thus $(D_1(W_0) = S^1$.

Figure 2.1 Case of water users with identical demand curves



Source: The Economics of Water Use (Zilberman, D., 1991,

Let Xi^j denote water used by the user i under state of nature j. Figure 2.1 shows that when supply is low, the senior rights holder will use all the available water $X^1{}_1 = S^1$, and the junior rights owner will not use any water ($X^2{}_1= 0$). When supply is high, the demand of both will be met, given the same diversion cost of W_0. This means that, $X^2{}_1 = X^2{}_2 = S1 = (S^2/2)$. The consumer surplus when water supply is low is equal to the area of the triangle AW_0G in figure 2.1. The consumer surplus is AW_OH, when the supply is high. Suppose water trading is allowed and costless; in this instance, the price of water at the low supply period will be W^1 and both users will consume $S^{1/2}$ units of water. The economic surplus in this period will be equal to the area AW_0GD. The transition to market will not affect the outcome of the high supply period, since market price will be

W_0. Therefore, there is a substantial gain equal to ACD of switching from a prior appropriation system to one of water trading in periods of low supply (Zilberman, 1991).

Market-based system creates incentives for water users to conserve water which, as a result creates incentives for the adoption of water conserving irrigation technologies. Increased production, increase in crop values, as high valued crops are substituted for low value ones will be the gains attained. This suggests that the move to a market system from the prior appropriation system may provide additional social benefits (Shal et al., 1993; Dinar and Letey, 1991). High transactions costs may deter the transition as water transfers in a market-based system may produce third party impacts where beneficiaries other than the direct water users are affected by changes in water supply, but do no have access to markets, as in the case of recreational uses of in stream flows (Colby, 1990; Gisser and Johnson, 1983). In an example such as this, if these transactions costs are greater than the gains from trade, then the transition to market is not welfare improving or socially more beneficial. In addition, political considerations may prevent the establishment of a water market even when it is welfare improving.

The insufficient management of water allocation has significant equity implications as most losses are experienced by downstream users. Many irrigation systems consist of long, poorly lined canals, causing losses of up to 50%, which result in low efficiency levels (Repetto, 1986). A great deal of the growing research on management of water resources is the economics of collective action as water is seen as a public good and a common-pool water resource. The design of institutions for the collective management of resources has received considerable attention (Ostrom, 1992; Tang, 1992; Wade, 1987). This interest stems from the realization that neither centralized state management nor decentralized privatization is an effective way of managing water resources (Ostrom, 1992; Wade, 1986; Evans, 1996).

Localized water users organizations (WUAs), which provide rules for water use as well as their implementation, have been found to be highly effective in managing public good and common-pool resources (Ostrom et al., 1992). WUAs have been successful in the management of collective goods through their impact on reducing transaction and information costs and in increasing the capability for activity coordination (Ostrom, 1992). We will cite some examples of the competence of WUAs in later chapters. Empirical evidence indicated that the establishment of externally funded irrigation projects has often resulted in the destruction of local institutions, and thus a decline in the efficiency of local irrigation (Ostrom, 1992; Baland and Platteau, 1996). The evidence implies the importance of institutional considerations in the development of new irrigation schemes.

Normally, ground water and surface water can be managed collectively; where the optimal management of the system depends on the stocks and flows of the two water sources over time. According to Zilberman, surface water canals have been established in many regions to compensate or supplement depleted groundwater aquifers. And in other instances, groundwater reservoirs have been established as buffer stocks to augment the use of surface water supplies in times of low supply. There is a growing literature on the economics of the conjunctive use of ground and surface water (Boggess et al., 1993; Tsur, 1990; Burt, 1964). It was concluded that the optimal management strategy will require pumping groundwater during dry years and increasing the aquifer with extra surface water during wet years. Even though water costs may differ, this strategy results in a more stable water supply.

2.5 The Economic Analysis of Water Projects

The primary economic tool used to weigh out the merits of investing in water projects has been the cost-benefit analysis (CBA). In spite of its simplicity and intuitive appeal, CBA's major fault is its dependence on the assumption of additive utility over time, which is unrealistic and may lead to flawed policy evaluations, ignoring issues of intertemporal substitution (Keen, 1990). Economic analysis of water projects should generally consider various issues among which we would mention a few prominent ones. With the development of water projects, the issues of uncertainty and irreversible outcomes, such as the elimination of ecosystems, have to be mainly considered. Arrow and Fisher (1974) argued that the appropriate measure for project assessment and evaluation is the expected discounted net benefits, which are obtained by computing discounted net benefits with and without the project and then applying the expectations operator to uncertain parameters. By measuring this way, the value of waiting for future information in the face of uncertainty is incorporated into the project analysis.

Negative environmental externalities have accompanied many water projects, which creates high social costs that are normally not accounted for in CBA. This has to be taken into consideration with any project evaluation as water projects that may seem to be welfare improving may in fact be a drain on social resources. Water-logging as previously described is a major environmental externality and usually happens in a situation where percolating water from irrigation collects and begins to build up at subsurface levels, posing a threat to agricultural productivity. The methods available for preventing waterlogging problems, although having their faults, are quite effective, they include a drainage system which removes accumulating groundwater or a system of reusing percolated water for irrigation. The cost of preventing or reducing environmentally damage associated with drainage and all other environmental externalities must be included in the economic analysis of water projects so as to paint a true picture of the costs and benefits associated with the project; net benefits of all components of the project should be maximized. Not paying attention to externalities such as these and their associated costs will normally lead to overinvestment in water projects.

The economic analysis of water projects should also include institutional considerations as institutional arrangements under which water is managed is a vital determinant of the efficiency and equity of water use. It provides an insight as to what the optimal mix of institutional and technical measures is. Lastly, a worsening of income distribution occurs if the benefits of the water project are captured by wealthier members of society while the costs of the project are borne by all, or perhaps disproportionately by the poor occurs when careful considerations of equity are not included in the analysis of water projects. Water projects are often located in low income areas which mean that any negative impacts associated with such projects, including the need for relocation, will be borne mostly by the poor. According to Zilberman, one method of tackling such equity concerns so that the benefits of the project are positive across all groups involved will be to expand the geographical scope of the analysis, in order to include all the costs that the project produces and implement compensation schemes from the winners to the losers (Howe, 1996; de Janvry et al., 1995).

2.6 Summary

The emphasis in water economics research has shifted from the expansion of new sources of water towards improving the efficiency of existing uses. We have examined a few of the several foundations dominating the water economics literature, ways to improve water use efficiency at the farm, community, national and international levels of analysis. I have shown the importance of environmental factors in determining optimal technology and water use patterns. The importance of institutions in determining water use efficiency is a greatly emphasized in this chapter. The economic analysis of water projects should include uncertainty, externalities and equity issues in order to determine actual trade offs facing society when making such public investments, and thus gearing towards an efficient allocation of resources. The potential for improving incentives leading to efficient water use through price reforms and the important role of institutions which promote collective action in overcoming problems arising from the public good characteristics of water resources are the focus of chapter 4 on demand side management of water resources.

Chapter 3. Review of Literature on Water Resources & Economic Development

The literature falling in the boundary between water resources and economic development has been said to be too vast to allow a single study such as this thesis to fully capture the entire picture. Nevertheless, it is possible to identify certain general features of the existing literature on the subject. Over the past decade or so, the literature has focused more on environmental concerns, social issues and institutional alternatives and as water is emerging as a global development issue, the literature is also showing an increasing shift towards international aspects of water. The core here is not only on water issues of transnational basins and those related to global dimensions but also on cross-country comparisons of policies and institutional structures that allow countries to share information and learn from mutual experience.

The volume of the literature to be discussed in this thesis covers and illustrates the sectoral and general problems of water, particularly from a developing country's perspective, where water is and will be a major constraint for socio-economic development. On the global level, irrigated agriculture is by far the largest consumer of water among various users, and concern over improving water use efficiency in this sector has been widely reflected in the water economics literature.

3.1 Literature on Allocation of Water Resources

By 2025 more than 3 billion people will be living in "water-stressed" countries (Postel, 1999) and by 2050 nearly 1 billion people living in the Middle East and North Africa will have less than 650 m^3 of water per person, a severe water shortage by any standard. Groundwork examination of water sector across sample countries shows that the key issue is no longer resource development and water quantity but resource allocation and water quality. Water use is distributed into three major categories namely agricultural, industrial, and domestic uses. Domestic use comprises of drinking water, private homes, public services, commercial establishments and municipal supplies. According to statistics from the World Bank, agriculture is by far the largest user of water, accounting for more than 70 % of water usage worldwide and more than 90% of water in low income developing countries.

There is an urgent need to formulate and implement sustainable[3] water management strategies in many parts of Africa. In 1992, 88 % of allocated water in Africa was for irrigation, 7 % was for municipal use, and 5% for industrial use. This distribution among these sectors is quite the norm in many low income developing countries, as priority is usually given to agriculture. The availability of water can vary greatly from season to season and from year to year. Some river basins, such as the Ganges and Mekong, have distinct dry and wet seasons each year. All through much of the developing world, the freshwater supply comes in the form of seasonal rains. Water is readily available to users at no cost or at a heavily subsidized price in many regions.

Therefore, neither water managers nor water users have incentives to conserve water; as a result water is overused and wasted instead of being treated as a scare resource. It should be noted that although high income countries i.e. developed countries apportion a much smaller percentage of water to agriculture than do developing countries, the total volume allocated to agriculture is still greater because annual usage

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[3] Sustainable is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs i.e. being able to continue into the future.

per capita in these countries are more than three times the volume consumed by developing countries (Robert MacLean; Joachim Voss, 2003).

An arising problem in recent years in developing countries has been the rapid increase in urban population; as this continues to grow the allocation of water will have to change. But if the agricultural allocations of water are reduced and partly shifted to these growing urban areas, the rate of food production, which currently is not keeping up with population pressure, may be further impaired causing retardation of economic development as the statement below further illustrates:

> *Twentieth-century water resources planning and development have relied on projections of future populations, per-capita water demand, agricultural production, and levels of economic productivity. Because each of these variables has always been projected to rise, water needs have also always been expected to rise. As a result, traditional water planning regularly concludes that future water demands will exceed actual water supplies. The water-management problem then becomes an exercise in coming up with ways of bridging this anticipated gap. (Gleick, P.H., 1998)*
>
> *Global consumption of water is doubling every 20 years, more than twice the rate of population growth. According to the United Nations, more than one billion people on Earth already lack access to fresh drinking water. If current trends persist, by 2025 the demand for freshwater is expected to rise by 56 percent more than is currently available. (Barlow, 1999)*

Many economists and environmentalists have asked the question: can there be an efficient allocation system which meets the water needs of the three sectors without hindering development? The water resources in a given country should provide for irrigation and the water needs of other sectors, depending to a large extent on the objective economic benefits obtained from the economy as a whole; this would quite appropriately be seen as a necessary condition of optimal allocation of water resources.

The literature points out that the efficient allocation of water would meet the needs of the three sectors and promote development. This can be achieved by way of increasing the efficiency of the current irrigation systems; where irrigation efficiency is the ratio between the quantities of irrigation water effectively used by the crops and the total quantities delivered. It is often affected by the design of the irrigation system, the degree of land preparation and the skill and care of the irrigator. If an efficient irrigation system could be derived, water can be managed well enough to meet urban needs without affecting food production. The past decade has seen significant degradation of existing cropland. Data are limited and definitions of damaged area vary considerably. Estimates of annual losses of agricultural land due to waterlogging and salinization range from 160,000 to 300,000 hectares (Tolba 1978; Barrow 1991), to 1.5 million hectares (Kovda, 1983).

A rising concern given the allocation of water resources in an economy would be that much water is wasted in all sectors of the economy: the agricultural sector, the household sector, and industrial sector. Estimates show that 60% or more of the available pumped water use in the urban areas are being wasted and/or not properly used (Robert MacLean; Joachim Voss, 2003). In the developing world, water use efficiency in irrigation is usually in the range of 25 to 40%, meaning that only 25- 40% of water in the system is used optimally. Irrigated croplands with high production potential have experienced much of this waterlogging and salinization. Even though, estimates vary substantially, it is clear that the degradation of irrigated croplands is a significant and growing problem that will continue to affect adversely and with increasing severity the existing irrigated production if not contained.

In the urban sector, in major cities in developing countries account 50% or more of direct water losses stemming from inefficiencies in water distribution; even though, water is usually reused somewhere else in this sector. The primary problem or challenge facing the allocation of water resources in a developing economy is centered on looking for ways where there is an overall improvement of efficiency in the agricultural sector which will increase crop productivity and simultaneously allow a reallocation of water from agricultural to urban and industrial sectors of the economy. Pollution of water from industrial effluents; poorly treated or untreated domestic and industrial sewage, runoff of chemicals in agriculture, and mining wastes are said to be the major problems associated with inefficient use of water resources.

3.2 Summary

Mark Rosegrant (1997) points out that nearly two thirds of the world's rice and wheat production is grown on irrigated land and growth in output per unit of land and water is essential to feeding as the increase in productivity requires more water use in the growing and ever needy population. Since there are a limited number of cost-effective new sources of water, the fast growing household and industrial demand for water will need to be met considerably more from reduction of waste in all sectors. Water savings in agriculture, to help reduce water scarcity and thereby assist in development, should be accompanied by improved efficiency in the urban and industrial use. The focus of this thesis; however, will be primarily on water use efficiencies in the current irrigation systems in the developing world. I hereby start by examining water management strategies; beginning with demand-side water management strategies.

Chapter 4. Demand-Side Water Management Strategies

There are many demand-side water management strategies to increase the level of farm efficiency. They include irrigation water management and installation of drainage systems to enhance sustainability of land use (Wichelns, Cone, and Stuhr, 2002; Caswell, Lichtenberg, and Zilberman, 1999).

4.1 Water pricing and Water Markets

Water pricing policies and market mechanisms are, in many cases, the key components of a framework needed for determining the allocation-oriented approach to water scarcity problems. The allocative role of water prices requires them to be based on the scarcity value or the opportunity cost of water. Observation of water prices for various uses seen in both developed and developing countries indicate that they are based on the average rather than marginal cost of supply, implying that they do not cover the full supply costs (Dinar and Subramanian, 1998). The situation is much severe in irrigation which accounts for a three-quarter share of total water use in most countries. Government involvement, political difficulties and implementation costs all make it difficult to adopt volumetric provision and marginal cost-pricing methods.

Water markets appear both in countries with formal water rights systems as well as in those without any formal system of water rights. Rosegrant and Binswanger reported that a review of international experience demonstrate that the promotion of intra and inter sectoral water allocation through markets in tradable water rights can have significant efficiency and equity gains. The major distress in developing countries, however, are the issues of creating the legal system of water rights, the physical structure for water measuring and conveyance, and the organizational mechanisms for enforcement and conflict resolution which together contribute a key challenge in these countries (Easter, Rosegrant and Dinar, 1999). Easter et al., (1997) gives six essential arrangements for an efficient, equitable, and sustainable water market. First, there should be institutional arrangements establishing water rights separate from land rights. Second, a management organization should be in place to help apply water trades. Third, a flexible infrastructure is needed to transfer water. Fourth, the system in place should be able to internalize third party effects by which we mean externalities. Fifth, there should be effective resolution mechanisms for water conflicts. And finally, attention should be given to equity concerns such as future and social goals. When these arrangements are distorted there are considerable implementation costs, market allocations are unlikely to attain first best results.

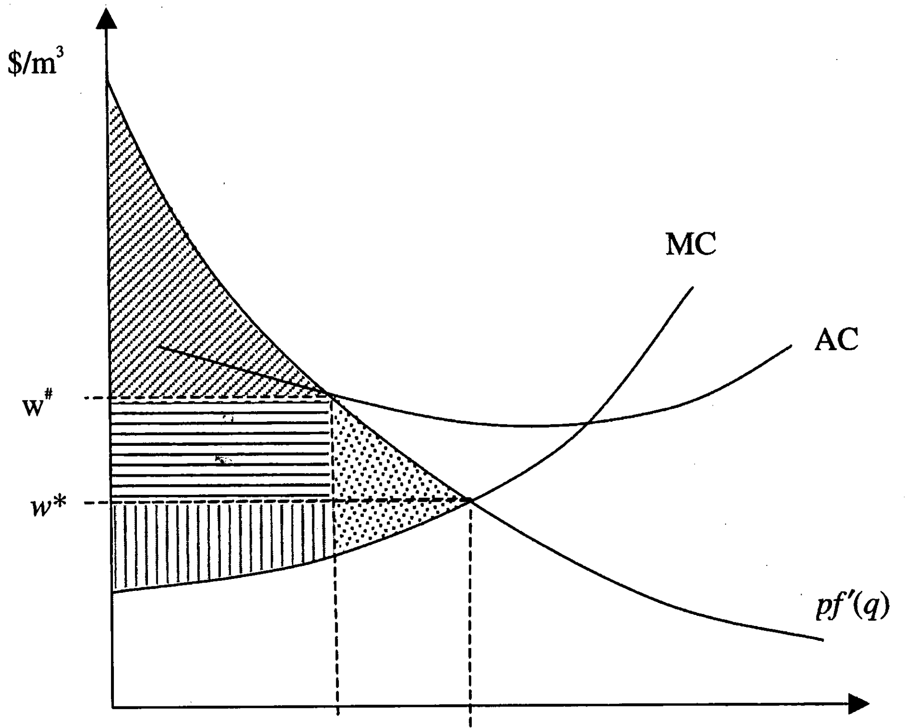
Furthermore, there is also the controversy when we consider the case of public goods. For large scale irrigation projects, water services satisfy the two characteristics of a public good “weak excludability and subtractability.” Easter et al. (1997) defines water services as having weak excludability because of the large number of farm plots and monitoring difficulties. In this situation, market forces will not provide the optimal level of investment and involving private companies will be complicated. Similarly, the provisions of goods in large portions i.e. flood control or large dam projects not readily divisible for private purchase by private companies also manifests weak excludability. Thus, it is debatable that unregulated markets may therefore be suboptimal for a country’s social or developmental goals in terms of poverty alleviation, food security, equity, and public health. However, overexploitation of these resources is commonly referred to as the "tragedy of the commons" (Hardin, 1968), which describes a situation when users of a resource, pursuing their own self-interest, ignore the effects of their actions on the resource and on other users. Given this, economists usually call for private water rights and the formation of water markets.

To encourage conservation, water utilities are advised to charge higher prices for water (Rogers, 1992). Nevertheless, users frequently have been able to use political power to prevent major increases in water prices, especially irrigation water. Water rates that may be accurate at one time may be inaccurate or inappropriate 15 years later if they have not been adjusted for inflation (Easter et al., 1997). Our focus on an efficient pricing of water will lie upon pricing irrigation water, as irrigated agriculture consumes most "70per cent to 90 per cent" of the water that is available in the world and the policies to improve efficiency in irrigation will provide benefits well beyond agriculture (Tsur, Roe, Doukkali and Dinar, 2004). Israel is known to have experienced a 50 per cent reduction in water use after there was an improvement in the water pricing system. Although, reviewing additional theory on water pricing is relevant, it is also beyond the scope of the thesis, so it is necessary at this stage to introduce several guidelines that will help when analyzing pricing methods (Tsur et al., 2004):

1. Marginal cost pricing (MCP) achieves efficient water allocation in that it maximizes the joint surplus of farmers and water suppliers.
2. Average cost pricing (ACP) is when pricing charged for water use are based on average costs guarantees a balanced budget of the water supply agency but entails a loss of efficiency. Farmers carry the burden of the welfare loss.

3. Block rate pricing can be used to transfer wealth between water suppliers and farmers, while retaining efficiency. Block rate pricing deals with the case where the charge per unit consumption is held fixed until the threshold is reached where a new per-unit charge is imposed for all consumption beyond the threshold.
4. The costs of implementing a pricing method are part of the supply cost and should be included in the variable costs (VC) and/or fixed costs (FC) of water supply.
5. From an efficiency viewpoint, the desirable pricing method is the one that yields the highest welfare after accounting for implementation costs.
6. Any charge intended to cover the fixed costs of water supply agency should be levied in a way that does not affect farmers' water inputs decisions. When irrigation water is derived from a stock source (e.g., lake, reservoir, aquifer) in an often unsustainable fashion, for example, if the stock shrinks over time or the quality of its water deteriorates, the price of water must also reflect the scarcity (i.e., depletion effect) and stock externality (i.e., effect of stock size on withdrawal cost).

Figure 4.1 Water Allocations under Marginal cost and Average Cost Pricing



Source: Tsur, Roe, Doukkali and Dinar (2004, 75)

The joint surplus under MCP is the entire marked area, while under ACP it is the area with vertical, horizontal, and diagonal lines. The Welfare loss or deadweight loss is represented in the dotted area. An efficient allocation of water resources maximizes the total net benefit that can be generated using the best available technologies and with the volumes available. An allocation of water resources that maximizes total benefits from the use of the resource across regions to maximize social welfare, when there are no distortionary constraints such as taxes, produces what we call "first best"[4] or Pareto

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[4] "First best" means that economically efficient allocation of water results in the highest return for the given water resource.

efficient as discussed in the previous chapters. When distortionary constraints are present, for example, informational, institutional and/or political, the optimal allocation under the constraints of resources is called second best. Under certain circumstances i.e. no externalities, full information, complete certainty, perfect competition and nonincreasing returns to scale, markets normally will achieve first-best "Pareto efficient" allocation as described above where the price is determined by marginal cost pricing (MCP) methods. Given that we are dealing with water resources, second best allocation is the best we can achieve given constraints.

Marginal cost pricing is opportunity cost pricing. This means that the price of water is equal to the sum of marginal costs of delivery and marginal implementation costs. Water supply costs usually include such factors as implementation costs i.e. the collection of water and fees, maintenance, infrastructure, extraction cost externalities, and social costs and benefits not just only delivery costs. Given this notion, the difficulty in marginal cost pricing is the ability to include all costs and benefits when determining the correct price. In addition, MCP does not take into account equity concerns (Seagraves and Easter, 1983; Dinar et al .,1997), in that in periods of scarcity, the marginal cost of providing water will be expected to increase and as a result will affect lower income groups.

Consequently, many developing countries have opted out of using MCP as for instance, we consider the fact that it is not only the farmers that benefit from irrigation services, millions of other people do, so technically the farmers should not bear the entire cost of delivery. When implementation costs are integrated into MCP, we are now considering the case of "second-best" allocation of resources, under which pricing water below its long run marginal cost can be seen as optimal and still considered Pareto efficient (Rhodes and Sampath, 1988). Farm level analysis suggests that MCP is necessary to achieve efficient allocation and can also be used with a limited influence on income distribution; nevertheless, the implementation costs are relatively high, even excessive in many cases. A combination of tiered pricing, which takes into account variable costs, and per-area charges, which takes into account fixed costs, can achieve similar results to volumetric pricing in terms of both efficiency and equity. They are preferred to volumetric pricing alone because they are better at cost recovery. It must be mentioned that implementing similar pricing policies in various areas may have varying impacts or results under different conditions.

Many countries are reforming their economies and setting macroeconomic policies that have direct and indirect impact on the performance of the irrigation sector. Irrigation system level analysis should be of importance, as it allows specific conditions too be taken into account. For example, equity issues, in particular, can be better handled at the irrigation system or project level than at the macroeconomic level. A combination of the system-specific approach and the economywide approach is advantageous for a comprehensive policy analysis on water pricing. One reason for the movement toward reform in the water sector across countries is that water resources are increasingly becoming a limiting factor for many human activities. We now consider two different cases in two countries implementing demand management strategies; China on pricing irrigation water and Mexico on institutional changes- water user associations (WUAs).

4.2 Country Example: Pricing Irrigation Water in China

This example of pricing irrigation water illustrates the need for sustainable water management in a developing country and the battle to also make it economically efficient. During the first 30 years after the establishment of the People's Republic of China, the Chinese government adopted a highly centralized planned economy system. In the water sector, the government paid for all investments in infrastructure, farmers contributed their labour, and water was free to all users. No attention was paid to either economic benefits or costs, but maintenance was neglected, and benefits began to diminish (Yaozhou and Bingcai, 2000). However, since the period in the late 1970s when China opened up to the outside world, the development of its water resources has changed considerably. Financing has been broadened, particularly through loans from the World Bank and the Asian Development Bank. Water laws have been introduced, a water pricing system has been established and operation and maintenance (O &M) arrangements for water projects have been strengthened.

China is a large agricultural country with more than 100 million ha of arable land, including 55 million ha of irrigated land. In terms of surface water, China's mean annual river runoff is 2,711.5 billion m^3, equaling 284 mm in depth (Tsur et al., 2004). And for groundwater, some is formed from precipitation that soaks into the ground, and the rest average outs to be an annual groundwater resources of around 828.8 billion m^3. According to the State Statistics Bureau, the cultivated land in China is 94.97 million ha, which is 9.89% of the national territory.

In 1996, there were 54.7 million ha of irrigated land, of which 51.2 million ha are used as farmland, 2.3 million ha for orchards and forests, 0.8 million ha for pastures, and

0.5 million ha for other types of irrigated land (Tsur et al., 2004). China's cropping patterns, with its various climatic conditions, can grow many different crops and it is a country known to have the most rotation and repeat cropping in the world. China's crops have very distinctive regional characteristics. The production of corn and beans is concentrated in the northeast, whereas North China crops are wheat, corn, edible oils, and cotton. Rice is the main crop in some regions in the south. Table 4.2.1 below shows China's cropmix, its cultivated areas, and yields.

Table 4.2.1 China: Crops, Cultivated Areas, and Yields, 1996

Crop	Cultivated area (1,000 ha)	Total yield (10,000 tons)
Grain	112,548	50,453.5
Rice	31,407	19,310.3
Wheat	29,611	11,059.9
Corn	24,498	12,747.1
Oil Plant	12,555	2,210.6
Cotton	4,722	420.3

Source: Shen and Su (1998)

China has been effective in adopting irrigation technologies. With its enormous population and increasing social and economic development, the pressures to conserve water resources were enormous. Flood irrigation is China's traditional irrigation method and as the largest water consumer, irrigation has attracted a lot of attention. China has, over the past couple of decades, been developing water-saving technologies and irrigation equipment, constructing pilot water-saving projects and establishing a water-saving irrigation service system. 15.2 million ha of water-saving irrigation projects had been constructed at the end of 1998, which consisted of 1.7 million ha of sprinkler, drip, and microirrigation and 5.2 million ha of piped irrigation, and 8.3 million ha had been treated to reduce canal seepage (Tsur et al., 2004). Canals are the main methods for water transfer and irrigation in China.

A key area of interest to point out here is that in the past, the central and provincial governments were the major investors and decision makers in irrigation projects and farmers, although the end users, were rarely consulted by the government about whether an irrigation project should be constructed and what should be its size. The story is entirely different in recent years as farmers can now express their views on planning, design, implementation, operation, and maintenance of irrigation projects.

China's water pricing methods and principles are regulated by China's central government, via state councils, and the relevant administrative authorities issue specific tariff standards. The provincial governments have worked out implementation regulations appropriate to local conditions, since the introduction of the State Council's Water Tariff method of 1985. The implementation regulations generally specify the tariff, collection method, and management requirements for different water uses such as reservoirs, irrigation districts, and pumping stations. Table 4.2.2 below summarizes pricing principles for different water uses:

Table 4.2.2 China: Pricing Principles for Different Water uses

Water uses		Pricing Principles
Agriculture	Graincrops	Water supply cost
	Cash crops	Slightly higher than supply cost
Industry		Supply cost plus profit of 4 - 6%
Domestic		Supply cost plus minimal profit

Source: Tsur et al., (2004,p. 90).

Summary

There is a movement toward a market-based pricing system. The State Council's Water Tariff Method of 1985 and the China Water Law of 1988, which is the legal basis for water pricing, are milestones in water-pricing history. However, the revenue from tariffs on irrigation water is still far below the supply cost in most areas. The issue of concern is how to increase further the irrigation water tariff to cover the supply cost fully; so that the increase will be consistent with a new reform program and adaptation of market economy concept.

The water tariff increases forced farmers to raise their own prices but history shows that, although generally not in favour of the water pricing reform, farmers in China are willing to pay higher but "affordable" water prices if they can receive better service in return. Most farmers do have some margin to take in an increase in the price of irrigation water, considering the relatively low share of water in total farming costs. This helped increase farmers' voice in water management and conservation and eventually reduced agricultural production costs. China's future water-pricing reform aims to promote high efficiency in water use, conservation, and proper allocation in its bid to ensure stable and sustainable development of water resources while stimulating its now stable economic growth.

Tsur et al. (2004) advised that in its gradual move towards market-based pricing systems, China should adopt basic pricing and volumetric water pricing, setting water quotas and charging more for water used in excess of quotas and decentralizing the price regulations authority. Whether China has gained significantly from developing its agricultural sector in that the sector is at a level where farmers have high incomes and there is a diverse crop mix is debatable. The water pricing system is said to have contributed to the rapid economic development achieved in China; undeniably an outcome of sustainable water resources management. Table 4.2.3 shows China's irrigated area, irrigation water use and total grain yields for the past decades:

Table 4.2.3 China: Irrigated Area, Irrigation Water Use and Grain Yields.

Year	*Effective irrigated area (million ha)*	*Irrigation water (100 million m^3)*	*Irrigation water as percentage of national water consumption*	*Population (100 million)*	*Cultivated area (million ha)*	*Total grain yield (100 million kg)*
1949	16	956	92.0	5.40	97.9	1,132
1957	25	1,853	90.0	6.46	111.8	1,950
1965	32	2,350	85.0	7.25	103.6	1,945
1980	49	3,574	80.5	9.87	99.3	3,206
1988	48	3,874	—	10.96	95.6	3,941
1993	50	3,440	66.5	11.85	95.1	4,565

Source: Tsur et al., (2004, p. 208).

4.3 Country Example: Institutional Changes in Mexico (WUAs)

Let us now look at a brief summary of Mexico's water supply and demand, its climate, its irrigation technologies, its water allocation and more importantly its pricing of irrigation water. Mexico is the fourth largest country in the Western Hemisphere; covers an area of about 2 million square kilometers (100ha = 1km2), where with most of its territory (2/3) being arid or semi-arid (Tsur et al., 2004). Mexico has pronounced wet and dry seasons, three main water sheds, and more than 100 rivers. The mean annual rainfall of 777 mm results in a mean annual runoff of 410 km^3 and slightly more than 62 km^3 of yearly renewable groundwater (Tsur et al., 2004). In terms of surface water, Mexico's three main watersheds are the Western or Pacific Watershed, the Eastern or Atlantic Watershed and the Inland Watershed, which do not empty into the sea. Two thirds of the country's 146 rivers drain into the Pacific Ocean. Groundwater is vital for the Mexican economy. Annual natural recharge in 459 aquifers has been estimated at approximately 48 km^3, with an extra 15 km^3 as induced recharge in irrigated areas (Tsur et al., 2004).

Agriculture has played a central role in Mexico's economic development; many of Mexico's agricultural workers are subsistence farmers, producing only enough to feed their families. Irrigation areas are of two types in Mexico: 79 large public irrigation districts, totaling a nominal area of 3.3 million ha, and more than 30,000 communal and private irrigation units with a nominal area of about 2.7 million (Tsur et al., 2004). Irrigated land is 3.2 times more productive than rainfed land. Corn, a nutritional staple for most Mexicans, is grown on about a third of the country's cultivated land but mainly in central Mexico. Other agricultural products grown for domestic consumption include barley and soybeans, whilst fruit and vegetables concentrated in Mexico's northeast is targeted mainly towards the US market. About 20% of Mexico's agricultural production is exported (Tsur et al., 2004).

In 1996-98 there was a global investment of approximately US$320million for modern irrigation systems to be installed on 365,000 ha, in 9,673 projects. Typically, the costs of administration and operation and maintenance (O & M) of the irrigation districts were paid by government and, through water fees, by users. In the early 1950s, farmers paid more than 85% of O & M and administrative costs; however, by the early 1980s their contribution to the budget had fallen to less than 20% (Tsur et al., 2004). There was clearly a steady decline of farmers' contributions towards operation and maintenance and together with the financial crisis of the 1980s, the system collapse and resulted in curtailing the resources not only for investment to expand irrigated areas but also for maintenance of the existing irrigation systems. Between 1982 and 1987, irrigated agricultural production declined at an average annual rate of 0.4%. By the end of that decade, an estimated 800,000 ha were fallow or underutilized because of the deterioration of infrastructure. In addition, at the end of the 1980s, the 3.3 million ha of land served by public irrigation systems were under heavy stress of being over irrigated and polluted (Tsur et al., 2004).

Given this damaging result, the government in Mexico decided that transferring the management of the irrigation districts to the users would be seen as the appropriate strategy in order to change the relationship between government and water users. As a result, Mexico's Irrigation Management Transfer program was created and its role is to ensure that water user associations (WUAs) had adequate financial resources in order to ensure self-sufficiency. To do this, it was essential to raise irrigation fees or water tariffs to cover the cost of operation, administration, and maintenance at the levels of both module and main canals and water sources. As expected, irrigation water charges increased in most irrigation districts and as financial self-sufficiency was attained, the transfer of management ensued. Water users now bear more than 70% of the O & M costs and even during droughts and financial crises, more than 90% of the users paid the water bills (Tsur et. al, 2004). WUAs are farmer managed associations that allocate the water shared by a group of farmers. They are managed by and operated with the interests of water users in mind, meaning that they substantially reduce the costs of implementing water pricing such as monitoring and enforcement costs (Easter and Welsch 1986b; Wade 1987; Zilberman 1997).

Public irrigation in Mexico has undergone considerably decentralization; the result in the transfer of control to WUAs has increased in O&M fee collection and provision of irrigation services. Unfortunately, agriculture has only contributed 7% of gross domestic product (GDP), even though, agriculture employed nearly one fourth of the nation's economically active population in the mid 1990. Between 1950 and 1990, Mexico's agricultural sector grew by only about 10%. A way to develop Mexico's agricultural sector and to raise farmers' income must rely on better management of its water resources. Economic principles treating water as a social and economic good to reduce misallocation and waste of the country's water as well as extensive environmental damage, is what the National Water Law and other water related fiscal laws in Mexico is now based upon.

Water can certainly be seen as a major influence in Mexico's social and economic development. The expanding use of water for irrigation, urban, and industrial uses has been based, for the last 75 years, on the development of hydraulic infrastructure and the implementation of policies to ensure adequate water management. Ever increasing population "about 98 million" growth and urbanization have increased the conflicting demands on Mexico's water resources. Conflicts arise between neighbouring cities and normally, between neighbouring states and regions. In Mexico, water resource management issues are in the jurisdiction of the central government, which has had to deal with rising number of problems that come with new approaches towards sustainable water management.

They include increasing gaps between those who have access to water services and those who do not; deterioration of water quality in rivers and lakes; downgrading of water services because of poor maintenance and weak technical and administrative capacity of the organizations in charge of providing them; and a general condition of water wastage and inefficient water-use practices (Tsur et al., 2004). At the centre of these issues, there is also the serious underpricing of water, which leads to inefficiencies in the allocation of this resource to its most advantageous use and affecting the volume and quality of water services required by the population and, thus, their economic activities.

Summary

In light of this concern, the Mexican government implemented a number of structural reforms in the water sector and the management of national water resources. Legal and institutional changes took place, and a number of strategies were employed to reverse the negative trends. While these institutional changes in Mexico are admirable, still they are not sufficient enough to address the key water sector challenges facing the country. Nonetheless, Mexico can now build on this solid institutional foundation to develop a more comprehensive framework for effectively tackling water quantity and quality problems across all water subsectors and uses. These changes will have an impact in the agricultural sector; particularly irrigated agriculture and would indicate that Mexico is in the right direction toward modern water management and irrigation and ultimately economic development.

Chapter 5. Supply-Side Water Management Strategies

Exorbitant costs are associated with building new large scale irrigation systems in Africa. The estimated cost is around $10,000 to $20,000 (USD) per hectare (FAO, 1993 a, b). Given these exorbitant costs, even double cropping of high value products may not be seen as profitable. Consequently, it is recommended in developing countries to avoid large scale irrigation projects. Such infrastructure should only be implemented if it is deemed desirable by majority of potential users i.e. those who incur the cost and the economical and social benefits outweigh the costs. Irrigation has been known to have its problem: low groundwater potential, water-quality deterioration, and poorly drained inefficient systems that cause waterlogging and salinization. Irrigation systems also have a substantial effect on the water cycle as it changes the chemical quality of available water and the timing of its presence.

Despite of its problems, irrigation is the best method to increase food productivity. It has been estimated that only 17% of the world's cropland is irrigated; nevertheless, these lands produce a full one-third of the world's total food supply. The argument is basically that when carried out correctly and with adequate drainage, irrigation can provide farmers with the control of water utilizations that is necessary to grow modern, high yielding crop varieties and increases the number of annual harvests. Seckler et al. (1998) estimated that improvements in irrigation efficiency alone could meet a reduction in one-half of the increase in water demand through 2025. Enhanced efficiency can occur at the field level, farm level, system level, and/or at the basin level.

Poor irrigation water management is often the primary cause of soil waterlogging and salinization as irrigation water itself adds salt to the soil. Considerable degradation of existing irrigated cropland has occurred over the past decade. Estimates of annual global losses of agricultural land due to waterlogging and salinization range from 160,000 to 1.5 million hectares (Rosegrant, M.W., 1997). Majority of this loss has taken place in irrigated cropland with high production potential. Furthermore, in some regions modern irrigation systems are not always compatible with traditional methods of cropping. Some modern irrigation systems that replaced the traditional lifestyles of dry land people often underrated the difficulty of the landscape and climate of the environment into which they are transplanted. Very basic elements of hydrology, such as the relationship between precipitation, vegetative cover on the watershed, soil condition and stream flow, are not well understood in many arid climates (Pearce, F., 1992). The following example in Senegal depicts this situation:

> *The River Senegal rises in the Fouta Djallon and flows northward through increasingly arid land; when it finally turns west towards the ocean, it borders on desert. In these areas of low rainfall, the river's annual flood is necessary to life. Towards the end of the rainy season, it overflows its banks and floods the broad alluvial plain of the middle valley, where crops are grown in the dry season after waters have receded. The valley's agricultural production systems traditionally followed the seasonal rhythm of the river: rainfed cropping and pasturing on the jeeri uplands, followed by flood-recession farming and grazing on the waalo lowlands. Over the period 1946-1971, it is estimated that on average 312,000 hectares were flooded on both banks of the river and 108,000 hectares cultivated….(Adams, A., 2000)*
>
> *The total area covered by irrigation schemes on the left bank in 19995 was 71,751 hectares; and the area actually cultivated, both seasons included, was 29,792 hectares....... (Ibid, p.11)*
>
> *Senegal River development schemes have not brought about development.....Instead of development, there has been destruction. By sweeping aside production systems which offered a degree of food security, Senegal River development schemes have made life even more precarious than before for many inhabitants of the Valley. Those who are excluded from irrigated farming because of high costs involved cannot now fall back on the waalo, because since the dams were built, the annual floods can no longer be relied on to provide crops and grazing and replenish fish stocks. All the future seems to hold for them is emigration to the volatile outer fringes of Dakar's urban sprawl. (Ibid, p.24)*

5.1 Small scale and Large scale Irrigation Projects

In Africa, cereals account for a large proportion of irrigated land yet only a small amount of total cereals in Africa are irrigated. This means there exist a huge potential to increase food productivity but the main area of contention is how to go about it. The International Irrigation Management Institute estimates that irrigated land could be tripled by means of small-scale, community based irrigation systems which provide the greatest potential for extensively improving crop production; especially in areas where rainfall is more uniformly distributed. In sub-Saharan Africa, the most irrigated countries are Sudan, Madagascar, and Nigeria. Many of the irrigation systems in these countries are said to be traditional systems, of which many function below their technical potential and efficiency. Economists call for improvement of the efficiency of traditional, small-scale irrigation systems that build water holding capacities and promote greater water access. A country example of Tunisia in the next chapter illustrates this quite well.

Madagascar is one of the leading countries in sub-Saharan Africa achieving irrigation potential. The irrigation systems in place in Madagascar adopted Asian farming methods, which have been noted to be highly successful in that part of the world. Therefore, such systems may be applicable to and advantageous to other regions in Africa. These small-scale irrigation systems used by farmers to grow crops for their families or for local markets are usually also referred to as micro-irrigation; which is seen as the use of water efficient technologies in the cultivation of fruits, vegetables, and orchard crops. The most commonly used methods are known as drip, or trickle irrigation wherein a network of porous or perforated piping, installed on, or below, the soil surface, delivers, water directly to the root zone. The appropriateness of these irrigation technologies may differ in other areas. They are more efficient uses of water in irrigation in that water losses from evaporation and seepage are extremely low when using these systems and also the fairly constant moisture maintained in the root zone helps to prevent salt concentrations from rising to high levels (Postel, S., 1996). The costs associated with drip system typically are around $500 to $1,200 per acre. Part of the system cost is a capital investment useful for several years and part of the cost is annual. Systems can easily be over designed. Growers without experience may want to start with a relatively simple system on a modest acreage and gain experience.

Madagascar can share this knowledge it has acquired which involves; community-based, farmer to farmer and technology transfer mechanisms with other parts of the continent. Clearly, large-scale irrigation involvements such as the Sardar Sarovar Dam in Western India and those in West Africa failed so such an alternative approach from Madagascar may very well yield much better results for the economy as a whole. Nevertheless, avoiding large scale is not an option as the negative upstream and downstream impacts of large irrigation projects can be avoided with better planning and management. The short term undesirable effects of large storage dams can also be overcome in the long run by adopting appropriate agricultural policies. The experience of farmers in the Tiga Dam area in Northern Nigeria which is discussed in depth in the following chapter tells a completely different story and fuels added controversy over large scale vs. small scale irrigation systems.

Developing countries could look for ways to effectively build on local knowledge, institutions, and solutions for better water management. This helps transform and develop the agricultural sector of an economy from a low-productivity, mostly at subsistence level, to a modern farm, exclusively engaged in high productivity i.e. diversified and specialized production geared to the commercial market. In addition, involvement of farmers in the development and management of small-scale or even large scale irrigation systems should be desirable wherein their involvement should start from the project planning stage to the design stage if progress is to be achieved. A huge emphasis is placed on participation by farmers and rural people in all problem solving processes to ensure reasonable access to productive resources. Better use of local knowledge, practices and resources brings greater self-reliance among farmers and rural organizations (Thompson, J. and F. Hinchcliffe, 1998.). As a result, it will lead to improving the rural infrastructure, access to markets, provide post-harvest assets, and mobilize and build the capacity of grassroots farmers' organizations leading to overall economic development.

Concurrently, since it is poor people in developing countries who are most affected by food shortages, it is appropriate to increase the use of agriculture systems that maintain and rely on the available efficient natural resource base in those countries. Much evidence around the world is growing to support the view that adopting sustainable agriculture can bring substantial yield improvements to farmers; these farmers many of whom lack access to the capital necessary to purchase external inputs, must often rely on internal resources such as rainfall. It must be pointed out at this stage that farmer controlled small scale irrigation has been given much credit in better performance than government-controlled large or small scale systems. These farmer-owned and managed systems can sometimes fail; however, the failed systems do not carry on operating.

Nonetheless, the fact that these significant small scale sector continue to exist without much help from the government shows that it is economically viable(Rosegrant, M.W., 1997); as seen in Zimbabwe where gardens were planted in small valleys known as dambos. These gardens are usually irrigated with water drawn from nearby wells and during the 1986-7 drought, dambos were the only lands in some areas that yielded any corn, and produced a variety of foods (McCulley, P., 1996). A careful review of successful, small scale irrigation systems recognized the following common characteristics:

1. Technology is simple and low cost; consisting of small pumps drawing water from shallow aquifers of rivers and streams.
2. Private individuals or entities were responsible for the institutional arrangements for operating the system.
3. Supporting infrastructure is efficient in permitting access to inputs and to markets for the sale of surplus production.
4. These small scale irrigation systems are said to generate high and timely cash returns to farmers.
5. The farmer, thus, becomes a very active and committed participant in different project design and implementation.

5.2 Summary

From an eclectic point of view, the negative environmental and social costs of irrigation projects are to be considered along with their positive contributions to food production and employment generation. As can be seen, irrigation expansion has played a key role in enhancing agricultural productivity and food production in the overpopulated regions of Asia (Rosegrant and Svendesen, 1993). Irrigation has also contributed to employment gains to millions in rural areas. For instance, Saleth (1997) estimates in India the cumulative level of employment created by irrigation projects developed during 1992-7 has been of the order of 18.39 million man-years. Improvements to existing systems by means of supply side management techniques have shown to reap a lot of benefits to those countries who practiced it. In spite of these benefits, the major issue facing many developing countries in Asia and Africa, however, is how to enhance and sustain the economic gains of irrigation in the face of declining irrigation investment and poorly performing irrigation systems. The following chapter exposes us to two countries on the African continent and their experience with water management practices.

Chapter 6. Experience from Countries

The case studies from two developing countries, Nigeria and Tunisia are the focus of this chapter. I would start with a broad description of Nigeria and its available water resources. The economic and social impact of large dams on communities inhibiting floodplains downstream and the changes that have occurred in over 30 years since the construction of the Tiga Dam (1974) in northern Nigeria will subsequently be reviewed.

6.1.0 Case Study: The Tiga Dam (1974) in Northern Nigeria

Nigeria is said to be rich in water, but more than half the population has no access to safe drinking water (Pearce, F., 1992). Nigeria as a whole has ample water resources, although they are subject to great regional and seasonal variation. The planning of major irrigation, flood control, navigation and hydroelectric schemes has been hampered in the past by the scarcity of data on evaporation, river levels, run off and river flow. Nigeria's arable land resources are extensive, the water supply is abundant though not well distributed, and the climate permits rates of growth close to the maximum attainable in any country. Nigeria's economic development and the improvement in living standards thus depend largely upon the growth and progress of the agricultural sector of the economy.

The water resources of Nigeria, though ample, are not evenly distributed among the different sections of the country and are subject to great seasonal variation. In the past, there were very few water control schemes in place and progress of water control was hindered by a lack of knowledge of the characteristics of Nigerian water flow and evaporation. This improved control of water resources can be of vital importance to several sectors of the Nigerian economy. Agricultural production in some parts of the North could be expanded by irrigation, which could extend the growing season to permit cultivation of new crops or to enable new crops to be grown in one year. Flood control could make farming possible in fertile areas now subject to annual devastation. Nigeria is well provided with rivers. The Niger and Benue rivers are important transport routes, but their level in the dry season precludes year-round navigation over much of their courses. More than half the country is drained by the Niger, through numerous tributaries of which the most important is the Benue. The Niger is about 2600 miles long, rising in French Guinea. About one-third of its length is in Nigeria; it crosses the country in a southeasterly direction down to Lokoja where it is joined by the Benue, which rising in Cameroon, flows through 500 miles of Nigeria. The Niger empties into the Gulf of Guinea through many mouths, forming a protruding delta.

Nigerian agriculture, which produces virtually all the food consumed in the country as well as 90% of the exports, is readily capable of expansion. Climatic conditions are favourable in much of the country, many varieties of crops and some livestock are well adapted to their environment, and land is abundant. To what degree agricultural expansion in the immediate future and over the long term will be achieved, depends on the nation's ability to succeed in overcoming or minimizing the effect of such limiting factors as soil deficiencies, inadequacy of water supply in certain areas, low-yielding plant varieties, prevalence of plant and livestock disease, and primitive cultivation methods.

Millions of people are dependent on the floodplains of Africa for their survival. Floodplains are particularly significant economic resources in the semi-arid regions of

West Africa (Adams, 1993a). To explain how floodplain agriculture works, we consider the three typical cropping systems, first as floodwaters rise, rice is cultivated. Second, as the water recedes, crops such as sorghum or cowpeas are planted and third, crops such as tomatoes, onions and peppers are planted under irrigation in the dry season on the banks of rivers and where water lingers in the floodplain. In northern Nigeria, close to the town of Gashuna, the Rivers Hadejia and Jama'are converge to form the River Komadugu Yobe, which flows on, eastwards, toward Lake Chad. There is usually confused drainage caused by the formation and the low gradients in that area and as a result during the rainy season, the rivers spill over, flooding the low lying land. The region is inhabited by four main ethnic groups: Bede, Hausa, Manga and Fulani. The total population of the towns and villages within the floodplain has been estimated up to one million people (Kimmage and Adams, 1992).

Construction of the Tiga Dam, on the Kano River west of Kano City in Northern Nigeria took place during 1971-74. The dam live storage capacity is 1283 * 106 m^3 (Adams, 1993). The dam provides water to irrigate the Kano River Project (KPR) (Adams, 1991) and supplies water for domestic and industrial use in Kano City. Closure of the Tiga Dam coincided with the Sahelian drought which aggravated the desiccating effect of the dam. The general effect of reduced rainfall and dam construction has been to reduce the overall extent of flood in the floodplain (Hollis and Thompson, 1993). However, there were differing results within the floodplain areas. Now let us take an in depth look at the impacts of the Tiga Dam construction and the responses to environmental change in the floodplains.

6.1.1 Impacts of the Tiga Dam

There are normally short term and longer term impacts of the dam construction. Short term impacts of the Tiga Dam among which include changes in agriculture, fishing and pastoralism, had effects on the secondary and tertiary sectors of the economy: many traders were made redundant and local craftsmen were negatively affected by the seasonal absence of a large part of the population and local decline in incomes (Stock, 1978). Longer term impacts of the dam construction, on the other hand, include an increase in production on irrigated farmland and in that area it increased production of rice, wheat, tomatoes, peppers, onions and cowpeas (Thomas, 1995a). Thomas' findings indicated that in the longer term, agricultural production has undergone significant expansion despite catastrophic impacts on producers in the years immediately following the Dam's closure.

Although shocking, this finding is supported by other studies of the floodplain economy, which emphasize the dynamism and productivity of floodplain agriculture, and contrast it with the high costs and low productivity of formal irrigation schemes upstream (Adams, 1991). However, it is prudent not to rush into such conclusions as this example of the Tiga Dam example in Nigeria is of rare occurrence. What is also surprising is that recent demographic surveys and analysis of production census data provide evidence to suggest that over the same period, the population of the floodplain has increased at a rate greater than the Nigerian national average due to both local increase and immigration from surrounding dry lands (Adams, 1993b; Kimmage, 1993; Thomas, 1995a). It would seem; therefore, that the economy and society have in some way adapted to the environmental changes caused by the Tiga Dam, that created such temporary problems in the short term.

Research on environmental change in floodplain villages over the last 20 years suggest five different ways in which socioeconomic response to environmental change have been made (Adams, 1991). They include rainfed farming on previously flooded land, expanded flood recession farming, increase in the extent of rice farming mechanization, the expansion of small-scale irrigation and increased off-farm income. Among which the expansion of small-scale irrigation and the increased off-farm income flourished extensively in the floodplains. The introduction of small petrol pumps, shallow tube-wells, and the associated provision of credit facilities and extension services have allowed expansion of dry season irrigation throughout the floodplain in the early 1980s (Kimmage, 1990).

The expansion of small scale irrigation and its impact was observed after the dam construction. By the 1990s, irrigated farms were found at almost every village in the floodplain, and for some villages, such as Tagama, irrigation was ranked as making the most important contribution to the village economy (Thomas, 1995a). Salaried employment was also of increasing importance in some villages in the floodplain. This enabled parents to send their children to secondary school and obtain jobs in the civil service.

6.1.2 Conclusion

To put in a sum, it is the innovativeness and enterprise of farmers' response to changes in the environment, and their rapid adoption of new technologies that appear to have helped them to escape from the disaster that seemed inevitable in the years following the completion of the Tiga Dam. While it is apparent that in the short term, the socioeconomic impacts of dams and drought were strongly negative, over the longer period the environmental changes caused by the Dam and drought gave added impetus to the diversification and expansion of agriculture. The poor record of large dams in terms of social and ecological impacts has been widely examined for several decades, but such accounts have frequently only focused on the immediate post-construction period. This case study, however, deals with the contra-conventional scenario, simply meaning that the adjustments to social and economic systems in the medium term create a very different story. Notwithstanding its known adverse impacts, dam construction as part of large scale water control schemes will probably continue to be a major political and developmental objective in sub-Saharan Africa, to meet the demand for water for urban consumers and industrialized agriculture.

The search for more sustainable strategies for river basin development must involve minimization of negative impacts in downstream areas. In addition, further strategy should be devise in policies to promote positive adaptation to environmental change in downstream areas. This case study suggests that it may be possible, in the medium term, to alleviate some of the adverse downstream impacts of dams by seeking to promote economic conditions and infrastructure that allow innovation and intensification in agriculture by producers themselves. Nevertheless, this case study does not necessitate or imply that the net balance of costs and benefits of dam construction over time will necessarily be positive. It will be noteworthy to emphasize here that the Hadejia-Jama'are floodplain have special conditions to take into consideration i.e. the low incidence of agricultural use of floodplain's "wetland" resources at the time when the Tiga Dam was built. It is partly this condition that has enabled farmers to respond in the way that has been above described and to avoid the wholly negative outcome recorded in so many other floodplains downstream of dams. Local water resources development in the floodplain through the initiative and innovativeness of individual farmers has been shown to be far more effective both economically and environmentally.

On the other hand, development in the Hadejia-Jama'are basin could have concentrated on providing the conditions such as: markets, improved communications, education, credit, access to small-scale technologies etc, needed to develop the floodplain's resources locally. This could have been not only been cheaper, but more environmentally sensitive which is likely to have more egalitarian, whereas, large-scale irrigation has regularly led to land being concentrated in the hands of a few relatively wealthy farmers. In closing, although the recent history of development in the Hadejia-Jama'are floodplain provides some insight about ways to compensate for costs of dam projects, this does not overturn the argument that dams proposed on undimmed rivers in sub-Saharan Africa should be subject to very rigorous appraisal.

6.2.0 Case Study: Tunisia towards Sustainable Agriculture Use

Irrigation systems in North Africa are typically inefficient and lack adequate drainage, resulting in severe waterlogging and salinization. In many regions of North Africa, groundwater sources are being severely overexploited, and freshwater aquifers are deteriorating because of seawater intrusion (FAO, 1993 a, b) thus, reemphasizing the immediate need to formulate and implement sustainable water management strategies in this part of Africa. A short case study on Tunisia; a country in the northern part of the African continent, illustrates these facts.

Hydrologically, Tunisia is a marginal country and it has adopted a number of distinctive methods of water management for agriculture. The central region supports modern dam irrigation, while traditional rainforest harvesting is practiced in the south; two contrasting techniques. Traditional management is defined as techniques dating back to ancient times relying mainly on human and animal labour; whereas, modern systems rely on machinery and advanced technology. In Tunisia, maintenance of traditional methods can reduce the negative side effects caused by modern technologies and support their positive characteristics. A mix of both methods could be seen as a foundation to sustainable water supply for the future. Tunisia faces a serious water deficit caused by low annual rainfall, distributed unevenly over space and time, and increasing water demand (Beaumont, 2002). The country can be classified into three climate zones: Mediterranean, semi arid and arid and they all experience different water availability. Given these climatic conditions, there exist a number of distinctive methods of water management for agriculture.

The northern Mediterranean area experiences an annual water surplus, where precipitation surpasses evapotranspiration and as a result this surplus supports modern reservoir-fed irrigation. The semi arid central part of the country experiences a shortage of annual rainfall and the number of rainfall days decreases gradually as we move southward. Even though, modern dams have been constructed in the north of the arid zone, traditional technology such as rainwater harvesting and terraced wadi systems predominate. The arid zone experiences an annual water deficit due to low rainfall and high rates of evapotranspiration. Communities within these areas largely practice traditional rainwater harvesting given that surface storage of water is unachievable. Research on water management in Tunisia suggests that traditional small scale water management can transform a hazardous environment into one of relative security meaning that these practices operate within a naturally defined carrying capacity, while at the same time maximizing economic benefits for users.

Conversely, modern dam irrigation enforces a human carrying capacity, and though it could promote economic gain it often leads to environmental degradation. The Matmata Plateau, in the south of the country, practice rainwater harvesting and the Zeroud Basin in the central grassland exemplifies dam irrigation. The Matmata Plateau falls within the arid zone, with average annual rainfall ranging from 100 and 250mm, depending on location (Golany, 1988). Actual evapotranspirative losses vary between 400 and 500 mm per annum resulting in a negative annual water budget of 200-300 mm (Frankenberg, 1980). Central Tunisia, on the other hand, can be divided into two geographical regions. To the west lie the mountains of the Dorsale and rainfall across the region is higher than in the south, varying between 200 and 350 mm per year and actual evapotranspirative losses reach 600-700 mm per year, resulting in a negative annual water balance between 300- 400 mm (Frankenberg, 1980; Guillaud and Trabelsi, 1991).

6.2.1 Traditional Rainwater Harvesting and Issues of Sustainability

In southern Tunisia, rainwater must be collected, concentrated and transferred to cropped areas quickly to minimize losses with evaporation and runoff because crops are at risk from physiological drought. Rainwater harvesting has largely been the norm in the

Matmata Plateau (Ballais, 1990). The climate in the Plateau, topography and soils altogether make rainwater harvesting very effective. The case study pointed out that all farmers interviewed in that area "Matmata" said that they practiced agroforestry, a type of rainwater harvesting, and that they were able to grow relatively demanding tress such as olives, figs, almonds, pomegranates and date palms. Annual crops which include barley, peas, lentils and beans, and fodder crops were also grown, especially alfalfa. The farmers explained that cultivation was primarily subsistence, but a limited surplus was sold at local markets (Hill and Woodland, 2003). It was also noted that rainwater harvesting in that region was largely decentralized; sites were managed on a collective and community basis as water is considered to be a communal property, with just enough consumed to meet community needs while avoiding wastage.

These types of systems make use of indigenous technological knowledge, on a small scale, without being dependent on central authorities. Local expertise got an understanding and an awareness of the reciprocal relationship between surface water and groundwater. Farmers explained the necessity of replenishing what they call underground water supplies in order to ensure water for community use in future seasons (Hill and Woodland, 2003). Rainwater harvesting on hillsides does help to increase infiltration[5] and thus recharge groundwater, which is drawn upon locally. The landscape of rainwater harvesting has been crafted by human labour (Head, 2000). It has been estimated, for instance, that similar systems in Kenya require 600 man hours per ha to construct 320 man hours per cultivated ha per year to maintain (Pacey and Cullis, 1986). Given these high human costs estimates, there is a threat to any region practicing such a system of a

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[5] Movement of water from the land surface into the soil i.e. the penetration of water through the ground surface into sub-surface soil.

decline in the total number of its inhabitants, especially the younger generation who are attracted to urban cities or cities abroad (INS 1994; Shah 1994). This emigration leads to abandoned terraces, increased runoff, and gully erosion in concentrated pockets. This erosion is evident around the villages of Tamezret and Matmata. If the population declines any more, dryland agriculture would become infeasible on the plateau, thus, threatening farming on the piedmont (INS, 1994).

The traditional management in this case was able to physically divide the continuum between hazards and resources, more geared towards the latter, through construction of jessour systems[6]. This was carried using subtle manipulation of the landscape at micro and local levels using trial and error practical experience and drawing upon a community memory that allowed prediction of future successes and failures. According to Graf (1988), a potentially hazardous environment of slope instability, soil erosion and drought was transformed into a secure environment by resourceful management. To sum up, the communities discussed in this section show the possibility of sustained subsistence production in difficult environments by practicing traditional techniques (Ballais, 1990). It is likely that such adaptability and flexibility will continue to sustain subsistence agriculture into the future, if it can survive the threats of modernization meaning new settlements and the attraction of employment by the fast developing service sector of major cities.

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[6] A type of runoff farming; this system can be found in the more arid (100-200 mm rainfall) and mountainous zone. In seasonal riverbeds, little dams of earth and stones are constructed.

6.2.2 Modern Dam Irrigation and Issues of Sustainability

Tunisia since independence has greatly extended irrigated farmland, improved technology, developed credit and modified the land tenure regime (Egger 1990; Martin Castellanos 1996; World Bank 1996; Dillman 2001). Much of the country has replaced community self-management of water with centralized government control. Water is paid for in cash rather than labour, with charges relating to volume consumed. The Kairouan Programme, initiated in 1975, centered on the construction of two large dams in the neighbouring Zeroud and Marguellil Basins. The Programme supported financially and technically by foreign investment and by the Canadian government. Its purpose was to reduce flooding in the Kairouan Plain, to develop irrigated areas downstream of the dams and to supply the city of Kairouan with an improved water supply (Guillaud and Trabelsi, 1991).

Water flow in the Zeroud and Marguellil Basins had been regulated for centuries by means of a network of small barrages and 30 local dams. The decentralized management system maintained a number of spreading areas, which irrigated 30,000 ha and replenished local water. The cost of these small-scale works has been estimated at only roughly $4 million USD, as they utilized local equipment and 40,000 local labourers (El Amanmi, 1986). In contrast, the cost of the single large dam at Sidi Saad constructed after the severe floods of 1969, was estimated at $44 million USD. The dam initially supplied an irrigated area of 4000 ha, which has subsequently been reduced to 1000 ha (El Amami, 1986). This means that even though it was effective in flood control during the heavy rains of 1990, it has produced an irrigated area just one-fourth of the size of the original, at more than ten times the cost.

This shows an apparent economic disadvantage when compared with small scale hydraulic works. However, in terms of long term sustainability the Sidi Saad Dam has been estimated to have the probable service duration of 87 years (Zahar, 2001). But then again, this figure falls short of the generational history recorded by dryland jessour systems. Statistics show that the annual increase in agricultural activity between 1975 and 1985 was 5.5% in the Kairouan Plain in comparison to 3.6% for the country "Tunisia" as a whole (Ministere de l'Economie, 1986). Nevertheless, the spatial and social distributions of development were largely uneven and this trend took precedence in the 1990s as modern developments and state structural adjustment policies favoured large landowners in the plains. The results following this were obvious; land distribution problems, with the bottom 46% of landholders possessing only 8% of land, while the top 3% own 35% (King, 1999).

Modern large-scale developments have provided no more reliability over space and time than the earlier traditional small scale works; nevertheless, modern hydraulic developments has been known to reduce devastating floods and allow individuals to rise above the level of subsistence which has aided the economic development process. The difficulty of small scale works in raising living standards above subsistence level is knowing how to integrate fragmented agricultural systems into markets.

6.2.3 Discussion

Traditional rainwater harvesting permits precise local control of water for the common good and it offers the possibility of rural livelihoods that can be understood by smallholders without the need for large amounts of credit, expensive inputs or costly infrastructure such as, the Sidi Saad Dam discussed above. Barrow (1999) points out that modern large-scale hydraulic works are symbols of prestige and development acquired since independence. It will require planning and management that are dominated by politicians and engineers, limiting the decision making of farmers; agricultural producers resulting in a centralized policy and often such a policy does not take into account the wider hydrological landscape. Surface water and groundwater are no longer used conjunctively across land units; however, the level of integration is critical to the long term viability of water resources as it helps restore the disequlibria of regional water imbalances.

A country example of the inability of governments to manage local water supplies and operations leading to an inefficient use of water resources given its large irrigation potential is seen in Egypt; where significant savings of water can be achieved through more direct local control of water resources (Radwan, 1998). A balance must be struck between large scale centralized development and small scale decentralized management based on modernized indigenous technology and undertaken with local participation in order to understand the environment and society onto which large scale development projects will embark (Adams et al., 1994). The value of small scale traditional water management must be supported in the south of the country in order to maintain rural populations and it must be reestablished in the north to complement modern dam developments. To summarize, the environmental, economic and socio cultural sustainability of traditional methods across the country, can reduce the negative consequences caused by inappropriate modern programmes while supporting their positive impacts.

6.2.4 Conclusion

The research concerning water management in Tunisia is outdated and was usually in French only in recent light have we seen case studies exemplifying contrasting water management techniques i.e. the traditional small scale rainwater harvesting and modern large scale dam irrigation. Using Tunisia as an example I have demonstrated how to evaluate both methods in terms of sustainability not only focusing on the physical environment but also by examining socio cultural issues and economic viability. This analysis offers a foundation for sustainable water use in agriculture, which subsequently leads to economic development. A good mix of traditional and modern water management strategies will ensure higher standards of living in the long term. Appendix 2 shows Tunisia as one of the leading countries in Africa utilizing its potential irrigated area and as a result having a much higher value added per worker in its agricultural sector during the past decade.

Chapter 7. Empirical Analysis of Water Use in Agriculture

Determining where water is best used and where its potential productivity is highest is of great interest. Increasing the price of water as a policy tool to help alleviate excessive water consumption behaviour has been said to be an efficient water management strategy. Nevertheless, because water is so essential for life itself it cannot be fully treated as a commodity and since crop irrigation is essential to food security, raising the cost of water may considerably increase the cost of irrigated produce. This in turn could affect a nation's competitiveness within the global market given that agricultural products are heavily subsidized in other parts of the world.

Unfortunately, this is often the dilemma associated with economic development resulting from sustainable water resources management in the agricultural sector of an economy. To understand this analysis further, we briefly review the growth theory and its implications. Most of the literature on growth theory mainly focuses on the determinants of aggregate economic growth; however, there has been less emphasis on sectoral economic growth. With the increased interest in growth theory, empirical work on economic growth has expanded enormously in the last decade. The sectoral growth literature builds mainly on the dual economy model originating in Lewis (1954) and Hirschmann (1958). This model seeks to explain economic growth by emphasizing the roles of agriculture and industry and the interplay between them. The dual economy model views the agricultural sector as the foundation of an emerging economy, a generator of the capital necessary for take-off toward the second stage of economic development, industrialization. The model explains that when industrialization has taken place, the agricultural sector becomes redundant. However, this dual economy literature essentially rules out two major issues, both of which seem quite intuitive, regarding the later stages of economic development.

The literature at first ignores the possibility that agriculture may be an important growth-promoting factor. And secondly, it rules out feedback mechanisms between agriculture and industry. I have also found that recent developments in the sectoral growth literature also reject this view of the dual economy model. Gopinath, Roe, and Shane (1996) address these issues, analyzing the possible link between agriculture and food processing. Productivity gains in agriculture are allowed to feed back into the food processing industry, where they lead to cheaper inputs. These lower priced inputs lead in turn to increased derived demand for primary agricultural products, thus partly justifying the price decline of agricultural products. The two sectors evolve interdependently over time, contrary to what the dual economy model predicts (Gopinath et. al., 1996).

Furthermore, Falkenmark (1997) highlighted and recognized that due to water constraints on food production; nearly 55 % of the global population would have to import food by 2025 to feed its growing population. In order to avert a "Malthusian precipice"[7], Falkenmark concluded that it would be necessary to secure regional and inter-regional food transfers to Northern China by intercontinental transfers to North Africa through the West Asia and South Asia belt. Intensive research on drought resistant crops would be necessary to safeguard food security for the remainder of Africa. Much of Eastern Africa today faces severe drought so evidently this argument portrays the pressing need for sustainable water resources management within the agricultural sector.

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[7] Malthusian precipice raises questions such as these: can that many people feed themselves? Can they do it without degrading the soil for the generations to come, or destroying other species? Will there be any wild places left?

Most economic analyses of policy intervention in the irrigation sector address questions at the farm or regional levels, or mostly at the sectoral level. The results of these various interventions differ, depending on the local institutional setups. However, many countries are also interested in valuing irrigation water resources and their services at the national level for other reasons. Aside from directly setting or estimating the value for water at the farm-level, policymakers are interested in the implicit impacts of macroeconomic policies on the irrigated agricultural sector, especially as it relates to agricultural trade reform. It is imperative at this stage to introduce a much broader perspective on economic development as there are other economywide factors to be taken into consideration. The most recent round of WTO negotiations in Doha, Qatar was centered on the issue of removing barriers to agricultural trade. For developing countries in particular, the foreign exchange they can potentially earn from growth in exports of crops is significantly important for financing imports, not only of food grain and meat products, but other intermediate factors of production that support advances in technology for all sectors of the economy, thus, stimulating economic growth.

If developing countries allow trade opportunities to prevail in their agricultural sectors, then the shadow price of water allocated to these crops will rise. This rise will likely not be regionally neutral, with some areas benefiting more than others do. For example, such policies will likely be more effective in farms that have access to a wider technological base. Similarly, large farms with better access to capital and information may be in a better position to gain from such policies. Further, micro- climates, differences in soil characteristics, and differences in the seasonal availability of irrigation water, among other factors, typically cause one irrigation district to specialize in crops that are distinct from other districts in the same country as we have seen from the experiences in chapter 6. Small farms may need some help in the form of improved information through extension services or cheap credit to be able to adjust to the changing environments associated with water pricing reforms.

7.1 Data on Agricultural Development

Examining empirical data built on this framework in order to refute or support our arguments thus far is a necessary step to take in this analysis.

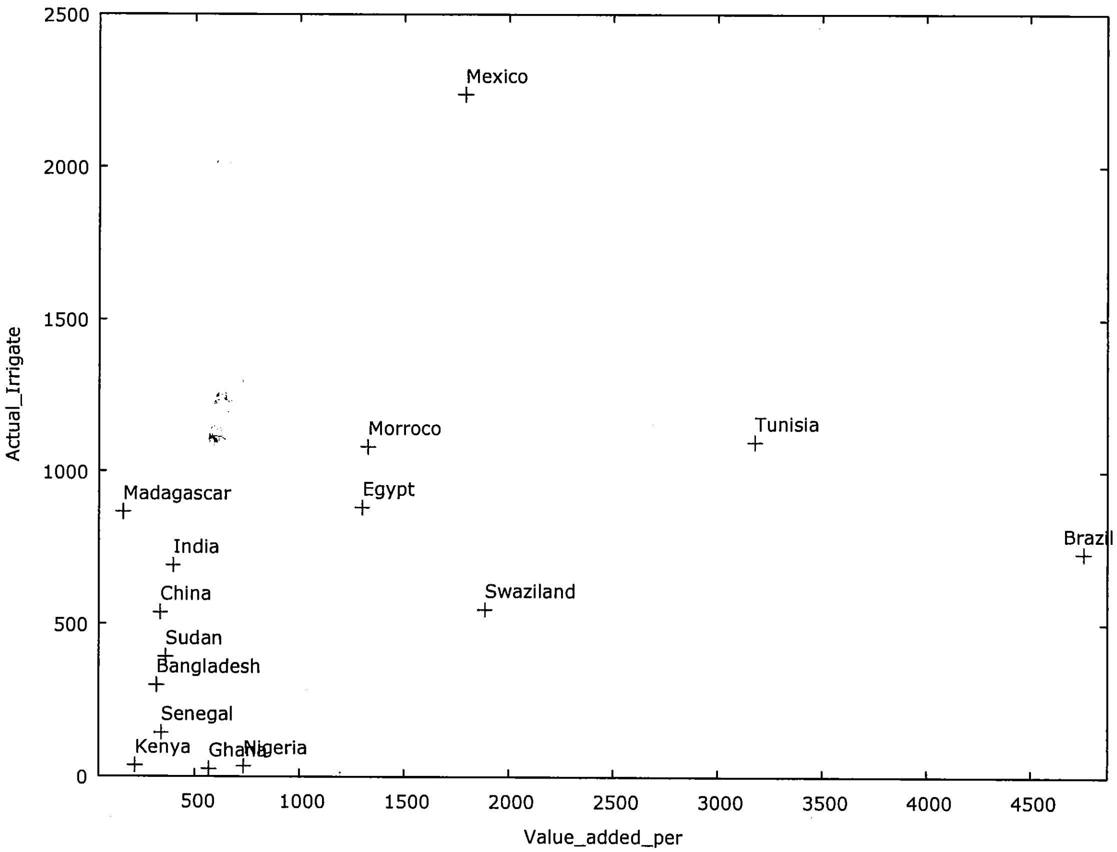
Many factors contribute to the development of the agricultural sector of an economy. This thesis suggests that sustainable water resources management in the agricultural sector plays a role in the overall economic development of a country. I would like to observe and examine available data on agriculture to see if there is indeed a trend to this concept. Data was extracted from the AQUASTAT database a link found on the website of the Food and Agriculture Organization of the United Nations (FAO). In addition, data on value added per worker in agriculture was taken from the text of Leading Issues in Economic Development (Meier, Rauch, 2005).

All tables and associated graphs both in the text and appendix 2 reflect the information provided by the cited sources but there is no certainty that the information is still current. Given the constraints and problems with gathering real data, only records of 16 countries are used in this analysis. The data range on these 16 countries, most of them developing countries are from the years 1990-2000. In an event where I observed missing data in a year, the most recent record given the range was taken. Value added per worked is expressed in US dollars and potential and actual irrigated area per capita are calculated and expressed in 10000 m^2. Because of the factors noted above, it will be misleading to apply too rigorous an analysis to the figures and all other information provided. Nevertheless, the following observations were noted:

7.2 Countries- Interpretation of Data

There are important differences in the agricultural sector from country to country. Such differences may reflect different objectives, different water sources, different degrees of water scarcity and irrigation schemes with different technologies, farm types or socioeconomic objectives. Only a few middle income countries are in the data set with the rest being developing countries, particularly African countries. In total, there are 16 countries, 15 of them are in our observation. Japan, the only developed country in this analysis is used as a yardstick and is not plotted on any graph. We observe at first the relationship between value added per worker in agriculture and actual irrigated area per capita in the years1990-2000. We can notice a weak positive linear relationship is formed in figure 7.3.1 on the next page:

Figure 7.3.1 Value added per worker & actual irrigated area per capita. (1900-2000)



The computer generated statistical results found in appendix 1 confirm that the relationship between the dependent variable, value added per worker, and the independent variable, actual irrigated area per capita is not a significant one; however, we can still observe a positive slope coefficient. This will suggest that there is some correlation between irrigation development and value added per worker. Given this results, it will be safe to say that developing the irrigated area in a country aids productivity in the agricultural sector. When we observe Tunisia alone, we see that the country's actual irrigated area per capita and its value added per worker produces a strong positively related correlation. Tunisia seems to be doing reasonably well when compared to the rest of the developing countries; the country has being more successful in developing its agricultural sector as the value added per worker is given at "$3,177" in the years 1990-2000. Tables A2.1 and A2.2 in appendix 2 show the value added per worker in agriculture, actual and potential irrigated area per capita for each country clearly.

Nonetheless, when we look at Mexico, the country with the most actual irrigated area per capita, we observe a lower amount "$1,791" for its value added per-worker in agriculture in the years 1990-2000. These two countries to some extent substantiate the case studies done on them in this thesis. Tunisia's experience with a mixture of traditional methods and modern developments is certainly gaining as value is added to the average worker in its agricultural sector; increasing productivity. Mexico, on the other hand, is still dealing with the serious underpricing of water needless to say, trying to find a comprehensive framework for effectively tackling water quantity and quality problems in irrigated areas.

Though, there is statistical evidence to suggest a possible relationship between irrigation development and productivity, other contributory factors, such as trade policies, high transportation costs, and the exodus of the rural population are in effect when we consider the case of the other countries. The correlation from figure 7.3.1 is only a weak one so one should be prudent and refrain from making firm conclusions.

Actual irrigated area per capital is now plotted as a percentage of potential irrigated area per capita in each country and the value added per worker is also plotted for all 15 countries. We can observe this in figures 7.3.2 and 7.3.3 on the next page:

Figure 7.3.2 Actual Irrigated Area as a % of Potential Irrigated Area (1990- 2000)

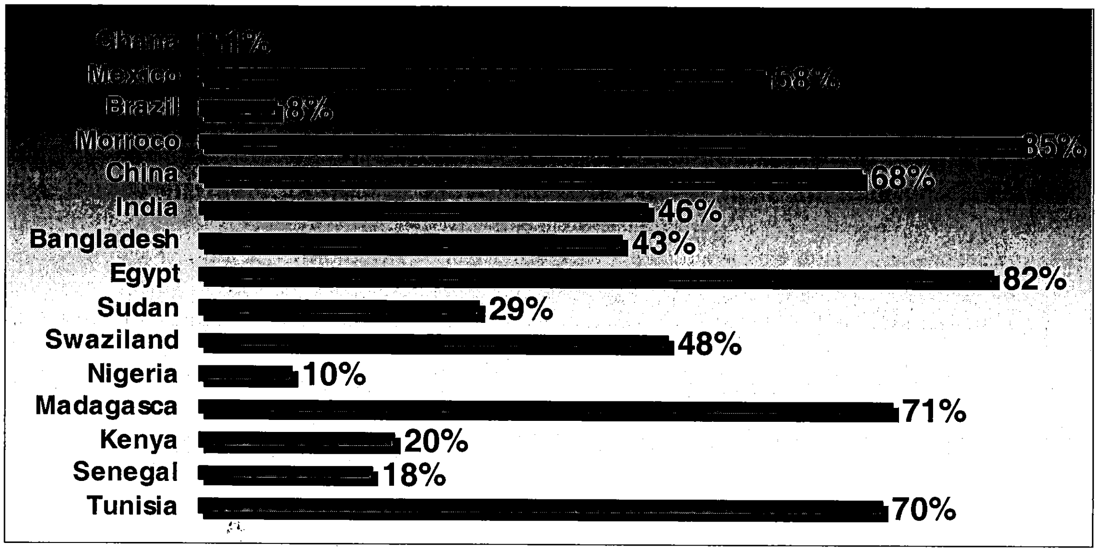
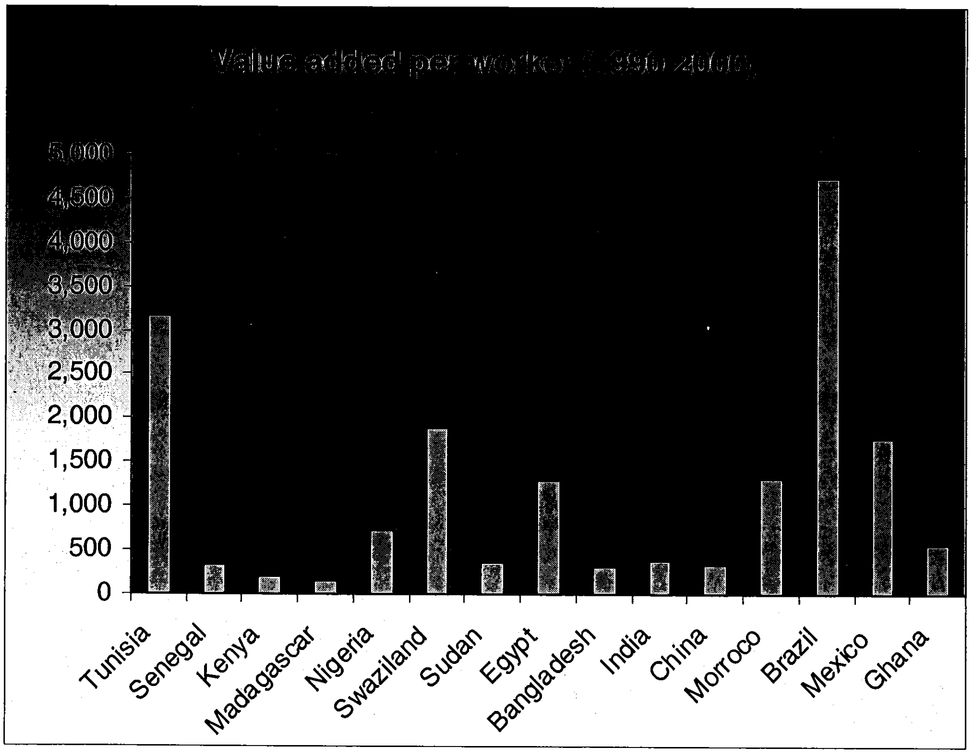


Figure 7.3.3 Value Added per worker ($) (1990-2000)



These figures give us very interesting considerations to take into account. We see that countries such as: Mexico, Morocco, China, Egypt, Madagascar and Tunisia have developed their irrigated area above 50% of what is available i.e. their potential irrigated area. By comparing both figures above, we observe that there are undoubtedly some winners and losers despite these countries developing most of their potential irrigated land. Madagascar is an obvious example of a loser in this context, the literature in Chapter 5 praises Madagascar for reaching its irrigation potential but this has not been met at farmers' level as value added per worker is considerably low, thus, implying further that there are other factors to taken into consideration.

In addition, it will make sense to assume that the arable land left for irrigation in the 6 countries mentioned above is too expensive to develop or probably not as valuable a land as those already irrigated. Given this assumption, these countries should therefore be looking for alternate forms of development in other sectors of their economies in order to foster economic development, as concern for future irrigation potential is questionable. On the flip side, developing countries such as Nigeria, Ghana, Bangladesh, Sudan, Kenya and Senegal should invest significantly in developing their agricultural sectors given that they have the available arable land to do so; there is the possibility of increasing the incomes of farmers and their productivity, thus, aiding development. In particular, policymakers in Nigeria, a country 90% dependent on its petroleum reserve, a depletable natural resource, should use its oil revenues to invest extensively in developing its agricultural sector. The value added per worker in agriculture in Nigeria is only at $732. The case study done on Nigeria describes the potential that could be gained given sustainable management of its water resources together with an efficient institutional structure to support development in the agricultural sector. Likewise, Ghana and Brazil should invest extensively in developing their enormous potential irrigated land in order to increase productivity in the agricultural sectors in both countries.

Japan the only developed country used in this analysis is a country that has achieved tremendous success in developing its agricultural sector as observed by the value added per worker data in Table A1.1. We see that the value added per worker in Japan in 1990-00 is reported to be $31,791. Using this figure as a measure to the rest of the countries in our analysis, there are several points what mentioning. The agricultural sector in Japan is not that big of a sector yet it is known to be heavily subsidized and protected; meaning that the government places stringent restrictions on imported agricultural products which increasing farmers' incomes. Not only is Japan's agricultural sector heavily subsidized, much of the EU countries have their agricultural sectors heavily subsidized; the Common Agricultural Policy (CAP) is a clear indicator of this. This implies that the countries in the EU can effectively dominate the international market for agricultural products.

Consequently, the countries in this analysis and most of the developing world, especially African countries, do not have a level playing field to be competitive in the international markets for agricultural products taken from this perspective. Farmers in these countries instead have to compete with the much of the dumping in the developing world while their products face many restrictions in the developed world. This is the main reason why trade liberalization on all levels is desirable i.e. not only among developed countries but also between all countries in order to have an efficient international trading market. Macroeconomic trade reforms would have a vital effect in the productivity of irrigated agriculture.

As productivity increases, development in the agricultural sector takes place by means of creating better governance and management that will invest in good infrastructure to reduce high transportation costs and granting economic incentives, such as producer price support policy or other taxation policies to farmers to help combat rural exodus. These results will have an all round rippled effect on all the other sectors; thus, ensuring economic development. Even though, many countries have moved toward opening their economies to world markets, trade reforms are still quite far from being complete. Many developing countries pursue policies of taxing export-competitive sectors and subsidizing import-competitive sectors.

As suggested sustainable water resources management in an agricultural sector of a country together with a non-water policy, such as a trade reform can effectively lead to increased productivity and economic development in a country. Our observations from the data have certainly given us great insight to the notion as prescribe by this thesis.

Table 8.1 Per capita water availability in 1990 and in 2025, selected countries

Country	Per captia water availability, 1990 (m^3 per person per year)	Projected per capita water availability 2025 (m^3 per person per year)
Africa		
Algeria	750	380
Burundi	660	280
Cape Verde	500	220
Cameroon	2,040	790
Djibouti	750	270
Egypt	1,070	620
Ethiopia	2,3600	980
Kenya	590	190
Lesotho	2,220	930
Libya	160	60
Morocco	1,200	680
Nigeria	2,600	1,000
Rwanda	880	350
Somalia	1,510	610
South Africa	1,420	790
Tanzania	2,780	900
Tunisia	530	330
North and Central America		
Barbados	170	170
Haiti	1,690	960
South America		
Peru	1,790	980
Asia/ Middle East		
Cyprus	1,290	1,000
Iran	2,080	960
Israel	470	310
Jordan	260	80
Lebanon	1,600	960
Qatar	50	20
Yemen	240	80
Europe		
Malta	80	80

Source: P.H. Gleick, 1992, Effects of climate change on shared fresh water resources, in I.M. Mintzer (ed.) Confronting Climate Change: Risks, Implications and Responses, Cambridge University Press, Cambridge, pp. 127-140.

From table 8.1 above, we see that some regions of the world are already unable to provide adequate supplies of water to their population, and more will run up against this constraint in the future. By the year 2025, over 30 countries, most of them developing countries, will be unable to provide 1,000m^3 per person per year, simply because of population growth. The table lists per capita water availability in 1990 and in 2025 for those countries with less than 1,000m^3 per person per year of fresh water. Water use of 500m^3 per person per year might even suffice in a semi-arid society with extremely sophisticated water management, such as Israel. But even there water resources scarcity is already causing political and social stresses. The price of water fails to include many of the most important costs of its use in most developing countries. Sustainable water resources management is indeed of paramount importance.

The different countries show that the net economic contributions of water resources have declined obviously as a result of inefficient use, poor management, declining water productivity and increasing environmental and financial costs. The inclusion of farmers in irrigation management and even ownership is seen as a way to stabilize, if not improve, most irrigation systems. One approach is to increase user participation in the operation of irrigation services. Water pricing is another approach used in achieving policy objectives such as efficiency, equity and cost recovery. Both water pricing and institutional arrangements under which water is managed are key determinants of the efficiency and equity of water use. Chapter 4 notes a variety of demand side water management strategies and the need for water use efficiency in irrigation is emphasized, with experiences and best practices taken from China and Mexico.

In addition, policymakers should always incorporate implementation costs when considering water pricing methods. Marginal Cost Pricing (MCP) can achieve an efficient allocation when it includes all the marginal costs and benefits associated with the allocation when determining the correct price. Priority has to be given to finding a balanced set of policies that treats water as an economic good, combined with a decentralized management and delivery structure, greater reliance on pricing and fuller participation of water users and other interested third parties. The policies needed to improve water management include making resource allocation in agriculture more flexible by removing subsidies and taxes that distort incentives and encourage misuse of resources, as well as by establishing secure property rights in land and water.

On the other hand, supply side water management strategies require that the economic analysis of water projects should generally consider various issues including the evaluation of small scale and large scale projects as well as assessing the negative environmental externalities caused by water projects. The case studies in chapter 6 on Nigeria and Tunisia show the negative and positive impacts from such projects vary from country to country as well as from region to region. It is also of grave importance to always examine the socio cultural issues and the economic viability in a country when building large irrigation projects. Traditional small scale methods should be considered together with modern large scale developments. As advised a good mix of implementing traditional and modern water management strategies could ensure higher standards of living in the long term.

Proper pricing and a balanced evaluation of competing investment opportunities should help achieve the best mix. In many developing countries, the state has provided for, constructed, and operated irrigation systems according to its plans, with little or no consultation with those who are to be served by the system. This approach has resulted in poor service and irrigation systems that are not sustainable over the long term. Too often, irrigation agencies have concentrated on new irrigation development at the expense of system maintenance. Once built, many agencies are not capable of performing the necessary operations and maintenance (O&M) and farmers are usually unwilling to accept the responsibility for maintaining the system when they were not involved in system planning and development. Sustainable water resources management will help develop and rehabilitate irrigation infrastructure thereby increasing cropping intensity through the involvement of the private sector and rural farmers in both irrigation scheme for development and maintenance. This will transfer agricultural technology to help raise small holder (farmers) productivity and diversification of their crop mix.

Since developing countries depend on agriculture as the dominant means of economic growth, water resources management is, therefore, one of the key instruments for expanding the scale of agricultural and industrial activities while at the same time supporting their growing and geographically dispersed population. Nevertheless, demand and supply water management strategies are more effective when considered together with non water policy measures such as trade policies. Incentives associated with trade liberalization in the economy as a whole and in the irrigated agricultural sector will lead to capital intensification in the production of crops where the country has a comparative advantage. Moreover, since the economy becomes more efficient and savings are now a higher percentage of a larger GDP, capital accumulation occurs in the other subsectors of agriculture. The resulting growth in agricultural GDP will increase social returns on investments in irrigation infrastructure such as canals, dams, and reservoirs and will enhance development in all sectors leading to the overall economic welfare of a country.

In closing, it is paramount to reiterate what the term sustainable means in the context of this thesis. Economists have long restricted the concept of sustainability to allocation decisions across generations. Any reasonable definition of sustainability should also include the idea of optimality. Having said that it implies we cannot use sustainability as the sole policy criterion, if it does not also imply efficiency. For this reason, sustainability is defined as achieving intergenerational equity in the most efficient way possible. The literature and empirical analysis carried on the premise of this thesis suggest that sustainable water resources management in the agricultural sector of an economy is undeniably an essential and a necessary condition for economic development albeit it not being a sufficient one.

Appendix 1

Results from statistical model:

Model 1: Heteroskedasticity-corrected estimates using the 15 observations 1-15

Dependent variable: Value_added_per worker in Agriculture (1990-2000)

Variable	***Coefficient***	*Std. Error*	***t-statistic***	*p-value*
Const	**593.324**	487.082	**1.2181**	0.24483
Actual_Irrigate	**0.909817**	0.574603	**1.5834**	0.13735

Mean of dependent variable = 1175.87

Standard deviation of dep. var. = 1301.12

Sum of squared residuals = 1.98689e+007

Standard error of residuals = 1236.27

Unadjusted R^2 = 0.161675

Adjusted R^2 = 0.0971881

Degrees of freedom = 13

Log-likelihood = -127.009

Akaike information criterion = 258.017

Schwarz Bayesian criterion = 259.433

Hannan-Quinn criterion = 258.00

A two-tailed test using the 5% significance level:

	0.10	0.05	**0.025**	0.01	0.001
df = 15	1.341	1.753	**2.131**	2.602	3.733

Appendix 2

Table A2.2 Value added per worker & Actual Irrigated Area per capita

Country Names	**Value-added per worker ($)[8] (1990-2000)**	**Actual Irrigated area per capita (10000 m2) (1990-2000)**
Tunisia	3,177	1098.38
Senegal	338	144.08
Kenya	213	36.15
Madagascar	154	866.35
Nigeria	732	33.83
Swaziland	1,886	547.53
Sudan	358	392.37
Egypt	1,300	881.68
Bangladesh	315	299.77
India	395	691.23
China	333	537.26
Morocco	1,326	1081.7
Brazil	4,754	732.06
Mexico	1,791	2237.02
Ghana	566	24.83
Japan	**31,791**	**707.23**

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[8] Note. From Leading Issues in Economic Development (p. 384-87), by Meier,G.M., & Raunch, J.E. (2005).

Table A2.3 Actual Irrigated Area as a % of Potential Irrigated Area per capita

Country Names	Potential Irrigated Area per capita (10000 m2) (1990-2000)	Actual Irrigated Area per capita (10000 m2) (1990-2000)	Percentage (%)
Tunisia	1565.1	1098.4	70%
Senegal	811.8	144.1	18%
Kenya	181.5	36.2	20%
Madagascar	1216.0	866.4	71%
Nigeria	356.0	33.8	10%
Swaziland	1138.2	547.5	48%
Sudan	1365.4	392.4	29%
Egypt	1081.1	881.7	82%
Bangladesh	690.0	299.8	43%
India	1504.1	691.2	46%
China	792.0	537.3	68%
Morroco	1279.7	1081.7	85%
Brazil	9450.1	732.1	8%
Mexico	3858.6	2237.0	58%
Ghana	1689.94	24.83	1%

Table A2.3 Bangladesh: Water Resources Utilization

Bangladesh	**1988-1992**	**1993-1997**	**1998-2002**
Arable land (1000 ha)	8008	7876	7997
Total population (1000 inhab)	114885	129191	143809
Rural population (1000 inhab)	91337	100554	109456
Water resources: total internal per capita (m3/inhab/yr)	913.9574	812.7501	730.1351
Water resources: total renewable per capita (actual) (m3/inhab/yr)	10537.86	9370.947	8418.402
Agricultural water withdrawal (10^9 m3/yr)			76.35
Domestic water withdrawal (10^9 m3/yr)	1.7	4.016	2.53
Industrial water withdrawal (10^9 m3/yr)	0.33		0.52
Total water withdrawal (summed by sector) (10^9 m3/yr)			79.4
Irrigation potential (1000 ha)	7553	7553	7553
Irrigation potential per capita(10000 m2)	**826.9376**	**751.1387**	**690.049**
Agricultural water managed area: total (1000 ha)	3100	3751.04	
Area equipped for irrigation: actually irrigated (1000 ha)	2738		
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**299.769**		
Area equipped for irrigation as perc of agricultural water managed area (%)	100	100	

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.4 Brazil: Water Resources Utilization

Brazil	1988-1992	1993-1997	1998-2002
Arable land (1000 ha)	51803	57740	58980
Total population (1000 inhab)	153632	165073	176257
Rural population (1000 inhab)	36882	34453	31058
Water resources: total internal per capita (m3/inhab/yr)	35266.09	32821.84	30739.2
Water resources: total renewable per capita (actual) (m3/inhab/yr)	53589.1	49874.9	46710.2
Agricultural water withdrawal (10^9 m3/yr)		33.43	36.63
Domestic water withdrawal (10^9 m3/yr)		11.5	12.02
Industrial water withdrawal (10^9 m3/yr)		9.94	10.65
Total water withdrawal (summed by sector) (10^9 m3/yr)		54.87	59.3
Irrigation potential (1000 ha)	29350	29350	29350
Irrigation potential per capita (10000 m2)	**7957.811**	**8518.852**	**9450.061**
Agricultural water managed area: total (1000 ha)	2700		2877.374
Area equipped for irrigation: actually irrigated (1000 ha)	2700		
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**732.0644**		

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.5 China: Water Resources Utilization.

China	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	123762	124143	142618
Total population (1000 inhab)	1189560	1249499	1302307
Rural population (1000 inhab)	840223	831635	808094
Water resources: total internal per capita (m3/inhab/yr)	2364.2355	2250.822	2159.552
Water resources: total renewable per capita (actual) (m3/inhab/yr)	2378.2314	2264.147	2172.336
Agricultural water withdrawal (10^9 m3/yr)	415	407.744	426.85
Domestic water withdrawal (10^9 m3/yr)	35	25.165	41.47
Industrial water withdrawal (10^9 m3/yr)	50	92.55	161.97
Total water withdrawal (summed by sector) (10^9 m3/yr)	500	525.459	630.29
Agricultural water withdrawal as part of total (%)	83	77.59768	67.72279
Irrigation potential (1000 ha)	64000	64000	64000
Irrigation potential per capita (10000 m2)	**0.0761703**	**769.5684**	**791.9871**
Agricultural water managed area: total (1000 ha)	50026.01	50990.91	
Area equipped for irrigation: actually irrigated (1000 ha)	44063.3	44680.3	
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**524.42387**	**537.2585**	
Area equipped for irrigation as perc of agricultural water managed area (%)	100	100	

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.6. Egypt: Water Resources Utilization

Egypt	1988-92	1993-97	1998-02
Arable land (1000 ha)	2519	2834	2922
Total population (1000 inhab)	58132	64019	70507
Rural population (1000 inhab)	33026	36816	40884
Water resources: total internal per capita (m3/inhab/yr)	30.964013	28.11665	25.52938
Water resources: total renewable per capita (actual) (m3/inhab/yr)	1002.89	910.6671	826.8683
Agricultural water withdrawal (10^9 m3/yr)		47.4	59
Domestic water withdrawal (10^9 m3/yr)		3.1	5.3
Industrial water withdrawal (10^9 m3/yr)		4.6	4
Total water withdrawal (summed by sector) (10^9 m3/yr)	58.3	55.1	68.3
Agricultural water withdrawal as part of total (%)		86.02541	86.3836
Irrigation potential (1000 ha)	4420	4420	4420
Irrigation potential per capita (10000 m2)	**1338.3395**	**1200.565**	**1081.108**
Agricultural water managed area: total (1000 ha)		3246	3422.178
Area equipped for irrigation: actually irrigated (1000 ha)	2585	3246	
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**782.71665**	**881.6819**	
Area equipped for irrigation as perc of agricultural water managed area (%)		100	100

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.7 Ghana: Water Resources Utilization

Ghana	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	2800	3600	4181
Total population (1000 inhab)	16165	18349	20471
Rural population (1000 inhab)	10032	10690	11243
Water resources: total internal per capita (m3/inhab/yr)	1874.42	1651.316	1480.143
Water resources: total renewable per capita (actual) (m3/inhab/yr)	3291.0609	2899.341	2598.798
Agricultural water withdrawal (10^9 m3/yr)			0.652
Domestic water withdrawal (10^9 m3/yr)			0.235
Industrial water withdrawal (10^9 m3/yr)			0.095
Total water withdrawal (summed by sector) (10^9 m3/yr)			0.982
Agricultural water withdrawal as part of total (%)			66.39511
Irrigation potential (1000 ha)	1900	1900	1900
Irrigation potential per capita (10000 m2)	**1893.9394**	**1777.362**	**1689.94**
Agricultural water managed area: total (1000 ha)		6.374	30.9
Area equipped for irrigation: actually irrigated (1000 ha)		3.888	27.913
Area equipped for irrigation: actually irrigated per capita (10000 m2)		**3.637044**	**24.827**
Area equipped for irrigation as perc of agricultural water managed area (%)		100	100

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.8 India: Water Resources utilization

India	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	161970	161298	160000
Total population (1000 inhab)	880166	965878	1049549
Rural population (1000 inhab)	651580	704924	754703
Water resources: total internal per capita (m3/inhab/yr)	1432.1617	1305.072	1201.03
Water resources: total renewable per capita (actual) (m3/inhab/yr)	2154.889	1963.664	1807.119
Agricultural water withdrawal (10^9 m3/yr)	460		558.39
Domestic water withdrawal (10^9 m3/yr)	25		52.24
Industrial water withdrawal (10^9 m3/yr)	15		35.21
Total water withdrawal (summed by sector) (10^9 m3/yr)	500		645.84
Irrigation potential (1000 ha)	113512	113512	113512
Irrigation potential per capita (10000 m2)	**1742.1**	**1610.3**	**1504.1**
Agricultural water managed area: total (1000 ha)	47430	50101	
Area equipped for irrigation: actually irrigated (1000 ha)	45039		
Area equipped for irrigation: actually irrigated per capita (10000m2)	**691.2**		

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.9 Japan: Water Resources Utilization

Japan	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	4714	4569	4418
Total population (1000 inhab)	124373	126151	127478
Rural population (1000 inhab)	44960	44230	44270
Water resources: total internal per capita (m3/inhab/yr)	3457.342	3408.613	3373.131
Water resources: total renewable per capita (actual) (m3/inhab/yr)	3457.342	3408.613	3373.131
Agricultural water withdrawal (10^9 m3/yr)	58.6		55.23
Domestic water withdrawal (10^9 m3/yr)	17		17.4
Industrial water withdrawal (10^9 m3/yr)	15.8		15.8
Total water withdrawal (summed by sector) (10^9 m3/yr)	91.4		88.43
Irrigation potential (1000 ha)			
Irrigation potential per capita (10000m2)			
Agricultural water managed area: total (1000 ha)	3012.31	3128.08	
Area equipped for irrigation: actually irrigated (1000 ha)	3012.31	3128.08	
Area equipped for irrigation: actually irrigated (10000 m2)	**669.9978**	**707.2304**	
Area equipped for irrigation: actually irrigated per capita (1000 ha)	0.067	0.070723	

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.8 Kenya: Water Resources Utilization

Kenya	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	4200	4400	4600
Total population (1000 inhab)	25146	28757	31540
Rural population (1000 inhab)	18424	19467	19457
Water resources: total internal per capita (m3/inhab/yr)	823.1926	719.8247	656.3094
Water resources: total renewable per capita (actual) (m3/inhab/yr)	1220.87	1067.566	973.3672
Agricultural water withdrawal (10^9 m3/yr)	1.566		1.01
Domestic water withdrawal (10^9 m3/yr)	0.403		0.47
Industrial water withdrawal (10^9 m3/yr)	0.08		0.1
Total water withdrawal (summed by sector) (10^9 m3/yr)	2.049		1.58
Irrigation potential (1000 ha)	353.06	353.06	353.06
Irrigation potential per capita (10000 m2)	**191.6305**	**181.3633**	**181.4566**
Agricultural water managed area: total (1000 ha)	73.025		
Area equipped for irrigation: actually irrigated (1000 ha)	66.61		
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**36.15393**		
Area equipped for irrigation as perc of agricultural water managed area (%)	91.21534		

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.9 Madagascar: Water Resources Utilization

Madagascar	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	2780	2820	2950
Total population (1000 inhab)	12650	14623	16916
Rural population (1000 inhab)	9550	10854	12474
Water resources: total internal per capita (m3/inhab/yr)	26640.316	23045.89	19921.97
Water resources: total renewable per capita (actual) (m3/inhab/yr)	26640.316	23045.89	19921.97
Agricultural water withdrawal (10^9 m3/yr)			14.31
Domestic water withdrawal (10^9 m3/yr)			0.42
Industrial water withdrawal (10^9 m3/yr)			0.23
Total water withdrawal (summed by sector) (10^9 m3/yr)			14.96
Agricultural water withdrawal as part of total (%)			95.65508
Irrigation potential (1000 ha)	1516.891	1516.891	1516.891
Irrigation potential per capita (1000 m2)	**1588.3675**	**1397.541**	**1216.042**
Agricultural water managed area: total (1000 ha)	1087		1096.041
Area equipped for irrigation: actually irrigated (1000 ha)	895		1080.691
Area equipped for irrigation: actually irrigated per capita (1000 m2)	**937.17277**		**866.3548**
Area equipped for irrigation as perc of agricultural water managed area (%)	100		99.11043

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.10 Mexico: Water Resources Utilization

Mexico	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	24200	24900	24800
Total population (1000 inhab)	86382	94287	101965
Rural population (1000 inhab)	23348	24610	25310
Water resources: total internal per capita (m3/inhab/yr)	4734.7827	4337.82	4011.18
Water resources: total renewable per capita (actual) (m3/inhab/yr)	5293.024	4849.258	4484.107
Agricultural water withdrawal (10^9 m3/yr)			60.34
Domestic water withdrawal (10^9 m3/yr)			13.59
Industrial water withdrawal (10^9 m3/yr)			4.29
Total water withdrawal (summed by sector) (10^9 m3/yr)			78.22
Agricultural water withdrawal as part of total (%)			77.1414
Irrigation potential (1000 ha)	9766	9766	9766
Irrigation potential per capita (1000 m2)	**4182.7994**	**3968.306**	**3858.554**
Agricultural water managed area: total (1000 ha)	5600	6256.03	
Area equipped for irrigation: actually irrigated (1000 ha)	5150	5505.31	
Area equipped for irrigation: actually irrigated per capita (1000 m2)	**2205.7564**	**2237.022**	
Area equipped for irrigation as perc of agricultural water managed area (%)		100	

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.11 Morocco: Water Resources Utilization

Morocco	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	8934	8980	8396
Total population (1000 inhab)	25500	27732	30072
Rural population (1000 inhab)	12791	12920	13003
Water resources: total internal per capita (m3/inhab/yr)	1137.2549	1045.723	964.3522
Water resources: total renewable per capita (actual) (m3/inhab/yr)	1137.2549	1045.723	964.3522
Agricultural water withdrawal (10^9 m3/yr)	10.18		11.01
Domestic water withdrawal (10^9 m3/yr)	0.543		1.23
Industrial water withdrawal (10^9 m3/yr)	0.322		0.36
Total water withdrawal (summed by sector) (10^9 m3/yr)	11.045		12.6
Irrigation potential (1000 ha)	1664	1664	1664
Irrigation potential per capita (1000 m2)	**1300.9147**	**1287.926**	**1279.705**
Agricultural water managed area: total (1000 ha)	1258.2		1442.639
Area equipped for irrigation: actually irrigated (1000 ha)			1406.56
Area equipped for irrigation: actually irrigated per capita (1000 m2)			**1081.72**
Area equipped for irrigation as perc of agricultural water managed area (%)	100		100

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.12 Nigeria: Water Resources Utilization

Nigeria	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	29922	28200	30200
Total population (1000 inhab)	91310	105616	120911
Rural population (1000 inhab)	57706	61945	65463
Water resources: total internal per capita (m3/inhab/yr)	2420.3264	2092.486	1827.791
Water resources: total renewable per capita (actual) (m3/inhab/yr)	3134.3774	2709.817	2367.03
Agricultural water withdrawal (10^9 m3/yr)			5.51
Domestic water withdrawal (10^9 m3/yr)			1.69
Industrial water withdrawal (10^9 m3/yr)			0.81
Total water withdrawal (summed by sector) (10^9 m3/yr)			8.01
Agricultural water withdrawal as part of total (%)			68.78901
Irrigation potential (1000 ha)	2330.51	2330.51	2330.51
Irrigation potential per capita (1000 m2)	**403.85922**	**376.2225**	**356.0042**
Agricultural water managed area: total (1000 ha)	956.535		972.211
Area equipped for irrigation: actually irrigated (1000 ha)	172.29		221.492
Area equipped for irrigation: actually irrigated per capita (1000 m2)	**29.856514**		**33.83469**
Area equipped for irrigation as perc of agricultural water managed area (%)	24.34004		29.85946

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.13 Senegal: Water Resources Utilization

Senegal	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	2320	2254	2460
Total population (1000 inhab)	7740	8748	9855
Rural population (1000 inhab)	4532	4789	5038
Water resources: total internal per capita (m3/inhab/yr)	3333.3333	2949.246	2617.96
Water resources: total renewable per capita (actual) (m3/inhab/yr)	5012.9199	4435.299	3937.088
Agricultural water withdrawal (10^9 m3/yr)			2.065
Domestic water withdrawal (10^9 m3/yr)			0.098
Industrial water withdrawal (10^9 m3/yr)			0.058
Total water withdrawal (summed by sector) (10^9 m3/yr)			2.221
Agricultural water withdrawal as part of total (%)			92.97614
Irrigation potential (1000 ha)	409	409	409
Irrigation potential per capita (10000 m2)	**902.47132**	**854.0405**	**811.8301**
Agricultural water managed area: total (1000 ha)		141.4	149.68
Area equipped for irrigation: actually irrigated (1000 ha)		69	
Area equipped for irrigation: actually irrigated per capita (10000 m2)		**144.0802**	
Area equipped for irrigation as perc of agricultural water managed area (%)		50.49505	79.95724

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.14 Sudan:Water Resources Utilization

Sudan	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	12900	16600	16233
Total population (1000 inhab)	26105	29397	32878
Rural population (1000 inhab)	18664	19618	20389
Water resources: total internal per capita (m3/inhab/yr)	1149.205	1020.512	912.4643
Water resources: total renewable per capita (actual) (m3/inhab/yr)	2470.791	2194.101	1961.798
Agricultural water withdrawal (10^9 m3/yr)	14.88	16.8	36.07
Domestic water withdrawal (10^9 m3/yr)	0.62	0.8	0.99
Industrial water withdrawal (10^9 m3/yr)	0	0.2	0.26
Total water withdrawal (summed by sector) (10^9 m3/yr)	15.5	17.8	37.32
Irrigation potential (1000 ha)	2784	2784	2784
Irrigation potential per capita (10000 m2)	**1491.642**	**1419.105**	**1365.442**
Agricultural water managed area: total (1000 ha)		1946.2	1863
Area equipped for irrigation: actually irrigated (1000 ha)		1197	800
Area equipped for irrigation: actually irrigated per capita (10000 m2)		**610.1539**	**392.3684**
Area equipped for irrigation as perc of agricultural water managed area (%)		100	100

Source: AQUASTAT Land and Water Development Division (FAO)

TableA2.15 Swaziland: Water Resources Utilization

Swaziland	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	179	178	178
Total population (1000 inhab)	887	983	1069
Rural population (1000 inhab)	683	756	819
Water resources: total internal per capita (m3/inhab/yr)	2976.325	2685.656	2469.598
Water resources: total renewable per capita (actual) (m3/inhab/yr)	5084.555	4587.996	4218.896
Agricultural water withdrawal (10^9 m3/yr)			1.006
Domestic water withdrawal (10^9 m3/yr)			0.024
Industrial water withdrawal (10^9 m3/yr)			0.012
Total water withdrawal (summed by sector) (10^9 m3/yr)			1.042
Irrigation potential (1000 ha)	93.22	93.22	93.22
Irrigation potential per capita (10000 m2)	**1364.861**	**1233.069**	**1138.217**
Agricultural water managed area: total (1000 ha)			49.843
Area equipped for irrigation: actually irrigated (1000 ha)			44.843
Area equipped for irrigation: actually irrigated per capita(10000 m2)			**547.5336**
Area equipped for irrigation as perc of agricultural water managed area (%)			100

Source: AQUASTAT Land and Water Development Division (FAO)

Table A2.16 Tunisia: Water Resources Utilization

Tunisia	**1988-92**	**1993-97**	**1998-02**
Arable land (1000 ha)	2908	2845	2771
Total population (1000 inhab)	8522	9193	9728
Rural population (1000 inhab)	3451	3486	3578
Water resources: total internal per capita (m3/inhab/yr)	492.25534	456.3255	431.2294
Water resources: total renewable per capita (actual) (m3/inhab/yr)	539.19268	499.8368	472.3479
Agricultural water withdrawal (10^9 m3/yr)	2.728		2.165
Domestic water withdrawal (10^9 m3/yr)	0.261		0.365
Industrial water withdrawal (10^9 m3/yr)	0.086		0.11
Total water withdrawal (summed by sector) (10^9 m3/yr)	3.075		2.64
Agricultural water withdrawal as part of total (%)	88.715447		82.00758
Irrigation potential (1000 ha)	560	560	560
Irrigation potential per capita (10000 m2)	**1622.7181**	**1606.426**	**1565.12**
Agricultural water managed area: total (1000 ha)	385		394
Area equipped for irrigation: actually irrigated (1000 ha)	322		393
Area equipped for irrigation: actually irrigated per capita (10000 m2)	**933.06288**		**1098.379**
Area equipped for irrigation as perc of agricultural water managed area (%)	100		100

Source: AQUASTAT Land and Water Development Division (FAO)

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