# Trends and Transitions in Asian Irrigation: What Are the Prospects for the Future?

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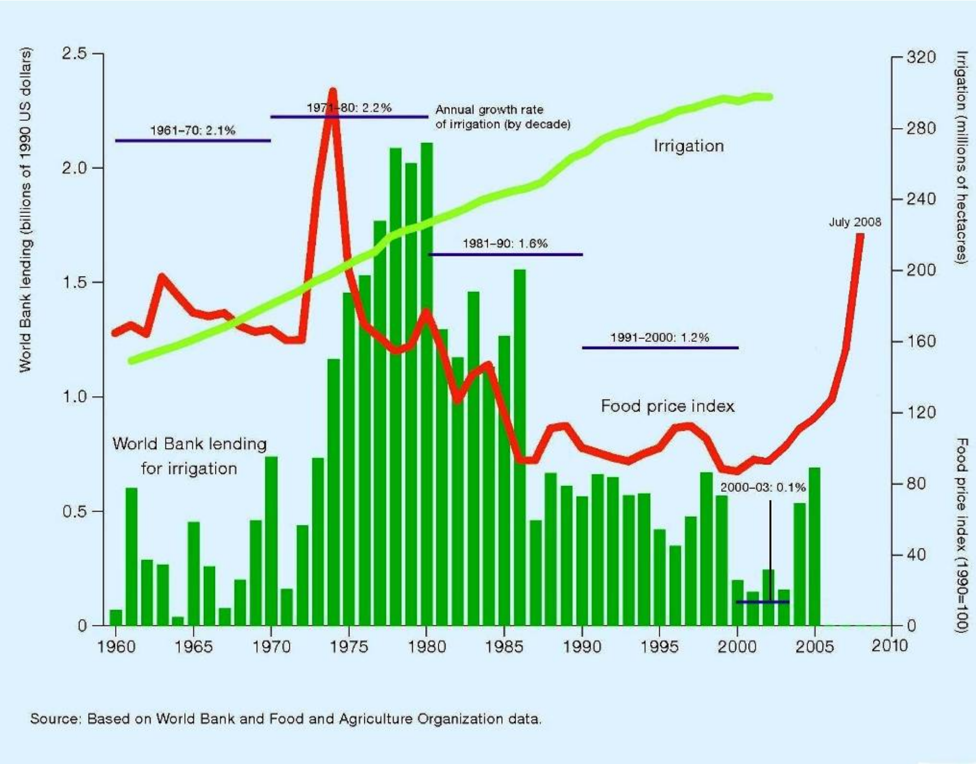
## 1. Introduction

In the 1960s, it was feared that much of Asia was in imminent danger of falling into the Malthusian trap of high population growth and low agricultural productivities resulting in widespread food crisis and famines. This was especially so since all Asian economies were overwhelmingly dependent on agriculture. Traditional agricultural practices and concomitant low productivities were no longer sufficient to sustain burgeoning populations. The food crisis in India in the mid-1960s was a grim reminder of a catastrophe about to be unleashed elsewhere in Asia. However, belying such doomsday predictions of starvation and deaths, most Asian countries emerged as food self sufficient through the 1970s and the 1980s. Asian economies avoided the Malthusian tragedy by embarking upon a Boserupian path of agricultural intensification. The use of high yielding varieties of seeds, high doses of fertilizers and other complimentary inputs such as timely and adequate irrigation came to be known as the Green Revolution. In South Asia, cereal production rose by 93% from 1970 to 1995, using only 4% additional land and boosted per capita food supply from 2,105 to 2,361 calories per day (Rosegrant & Hazell, 2000). In East and South East Asia, gains were even more impressive where agricultural productivities more than tripled and rural poverty declined rapidly. In China, poverty incidence reduced from 33% to 3% between 1979 and 2001(Gulati et al. 2005), and in India, poverty incidence reduced from 44.5% in 1983 to 27.5% in 2004-05 (Bardhan 2007). In this Green Revolution, irrigation was the key instrument that unlocked the huge potential for agricultural productivities in Asia.

While massive gains have been made in terms of increased agricultural production, alleviation of poverty thereby averting the dangers of famine and starvation, there is hardly any room for complacency. The Green Revolution, while solving a number of pressing issues had brought about what may be called second generation problems such as loss of soil fertility due to mono cropping, high input use leading to pollution of soil and water bodies, pest resistance, loss of bio-diversity and stress on natural resources. Total factor productivity has been growing at a slower pace than before and in many Asian countries (though not all), scope for further increase in productivity using current technologies are very limited. In the meanwhile, population in Asia continues to grow, albeit at a slower pace, Asian economies continue to diversify and integrate better with the global economy, thereby opening it up both to the opportunities and threats inherent in globalization. Similarly, people's aspirations and diets are changing, Asia is becoming increasingly urbanized and yet remains the home to the largest number of absolute poor, surpassing that of even sub Saharan Africa. Climate change poses particular challenge to poorer economies in Asia and would manifest itself through higher variability in temperature and rainfall, thereby directly affecting the agriculture sector.

Of particular interest to us in this paper is the state of irrigation and drainage in Asia. Asia accounts for more than 70% of the world irrigated area and roughly 2/3$^{rd}$ of this area is devoted to staple crop of rice and to a lesser extent wheat (Molden, 2007). Asia registered rapid increase in irrigated area since the last sixty years through the construction of dams and storage structures (from 1950s to 1970s) and then from increasing abstraction of groundwater resources (since 1980s). Investments in irrigation infrastructure, mostly in the form of surface water structures and canals peaked around early 1970s to mid-1980s in response to steep increase in food prices in 1970-73. Since then, food prices have been declining in real terms, though 2007-08 saw steep increase in food prices that precipitated a crisis. However, after a brief spike that caused global concerns, food prices, along with oil prices have again come down in recent months.

Figure 1. Rising irrigated area and falling investments and food prices



Source: Based on World Bank and Food and Agriculture Organization data.

Source: Comprehensive Assessment of Water Management in Agriculture, 2007

While irrigation has been central to the agricultural economies of Asia, the sector is under serious threat due to a number of reasons. For one, more and more countries of Asia face the threat of physical water scarcity and those who do not, are crippled by economic scarcity of water. Surface irrigation infrastructure has deteriorated due to lack of maintenance which often is a reflection of changing requirements of farmers that gravity flow irrigation can no longer provide. Crop diversification away from rice and wheat means that gravity irrigation structures constructed keeping in mind cereal crops do not readily adapt themselves to a more diversified cropping pattern that farmers in Asia are now moving towards. Massive efforts towards rehabilitation and more recently towards modernization of gravity flow systems have yielded less than satisfactory results. Irrigation reforms in the form of irrigation management transfer (IMT) or participatory irrigation management (PIM) have failed to deliver the promise of better and efficient delivery of irrigation services in South Asia, though they do hold promise in regions like Central Asia. While there are calls for 'reforming the reform process' (Molden, 2007), this paper takes a step further and calls for morphing or adapting existing gravity irrigation systems to changing socio-economic realities.

Increasingly, farmers in South Asia, north China and to some extent in South East Asia are turning to groundwater or surface water based lift irrigation which gives them a greater control over use of water. In Central Asia, however, usage of groundwater has declined since the disintegration of Soviet Union and this in turn has created a number of problems such as water logging and soil salinization. Groundwater boom, while bestowing a large number of benefits, have created its own set of intractable problems in terms of over-exploitation and depletion of groundwater resources thereby putting in jeopardy the livelihoods of millions of farmers who depend on it.

Globalization, urbanization, climate change, competing demands for water, changing aspirations, renewed emphasis on environmental water needs and the need to keep feeding millions of people in Asia continue to offer great challenges to the irrigation and drainage sector in Asia. The Asian countries and regions differ greatly from one another in terms of climate (arid vs. semi arid vs. monsoonal climate), economy (agricultural vs. industrialized; developing vs. developing vs. economies in transition), politics (multi party democracy vs. centralized system), development outcomes (poverty, child mortality, nutrition etc.). For the purpose of this analysis, Asia has been divided into four units, viz. South Asia, South East Asia, East Asia and Central Asia. Table 1, based on data compiled by the FAO shows some of the important demographic and agricultural indicators of selected countries in each of the region.

Table 1. Agricultural and demographic indictors of selected Asian countries.

| Region | Country | Agricultural Population (%) | Agricultural GDP (%) | Annual Growth Rate of Irrigation 1995-2003 | % Irrigated Land to Agricultural Land 2003 |
|---|---|---|---|---|---|
| South East Asia | Cambodia | 68.7 | 34.2 | | 7.0 |
| | Indonesia | 40.2 | 13.4 | 0.2 | 12.4 |
| | Lao PDR | 79.1 | 44.8 | 1.5 | 16.5 |
| | Malaysia | 14.3 | 8.7 | 0.1 | 4.8 |
| | Myanmar | 72.3 | 57.2 | 2.3 | 17.0 |
| | Philippines | 35.7 | 14.3 | | 14.5 |
| | Thailand | 45.9 | 9.9 | 0.9 | 28.2 |
| | Vietnam | 64.7 | 20.9 | 0.0 | 33.7 |
| South and Southwest Asia | Bangladesh | 47.0 | 20.1 | 2.9 | 56.1 |
| | India | 49.9 | 18.3 | 0.6 | 32.9 |
| | Iran | 24.2 | 10.4 | 0.6 | 40.2 |
| | Nepal | 93.1 | 38.2 | 0.4 | 47.1 |
| | Pakistan | 48.2 | 21.6 | 0.7 | 82.0 |
| | Sri Lanka | 48.6 | 16.8 | 3.4 | 38.8 |
| Central Asia | Kazakhstan | 17.2 | 6.8 | | 15.7 |
| | Kyrgyzstan | 23.1 | 34.1 | -0.1 | 76.0 |
| | Tajikistan | 30.4 | 24.4 | 0.1 | 68.3 |
| | Turkmenistan | 31.5 | 21.0 | 0.4 | 79.4 |
| | Uzbekistan | 24.4 | 28.1 | | 84.9 |
| East Asia | China | 63.9 | 12.6 | 1.1 | 35.6 |
| | DPR Korea | 25.3 | NA | | 50.3 |
| | Republic of Korea | 6.4 | 3.4 | -0.4 | 47.6 |

Source: FAO, 2007.

This paper is divided into six sections. In section 2, we will discuss the trends in irrigation and drainage in Asia with a special focus on the drivers of such change. Section 3 will discuss the impacts of irrigation, while section 4 will look into the future scenarios of water and food in Asia. In section 5 the need for irrigation reforms will be discussed while the last section will delineate the emerging challenges and opportunities for change.

## 2. Trends and drivers of change in Asian irrigation: 1980s to present

The two most important trends in irrigation development in Asia has been (a) rapid increase in area under irrigation across all regions from late 1960s to 1980s and then somewhat slower growth and (b) increase in area irrigated by groundwater and surface lift irrigation especially in south Asia and north China, while in Central Asia, area groundwater irrigated area has declined in absolute terms since mid 1990s.

There are numerous factors that have driven irrigation related developments in Asia. These range from demographics to changing diets to international food prices. Most often, drivers of change in the irrigation sector lie in the broader political economy and changes in developmental thinking. Economic development and hunger have always been concerns that have steered over agricultural and irrigation developments, but the way that these have been addressed differs over time. Globally, the issue of water was high on the agenda in the 1970s and 1980s with heavy investments in water infrastructure. Water, and especially development of water infrastructure, dropped in status on the international agenda in the 90s. During this period, concerns over social and environmental costs of water infrastructure rose, and emphasis shifted to demand management, economic incentives such as water pricing, and water management institutions. At the beginning of the millennium, water rose again to the forefront with an re-emergence of discussions about water infrastructure including dams and storage, but in a more balanced context, with more consideration of the social and environmental tradeoffs that water management and development decisions entail (SIWI 2004, World Bank 2003).

In agricultural water specifically, new paradigms call for considering agricultural water management in a basin context, the inclusion of rainfed agriculture in water discussions (blue and green water), more integration across sectors, appropriate roles for public and private sectors, the inclusion of fish and livestock in water and food debates. Good practice in agriculture is also increasingly more ecosystem sensitive, recognizing, for example, the importance of watershed protection, environmental flows and sustainable management of aquatic ecosystems, springs and aquifers.

At the same time there has been an increasing awareness amongst the environmental community of the importance of water, food and livelihoods issues. The agriculture and ecology communities have often confronted one another with unsatisfactory outcomes for most involved, but recently there have been real efforts to find common ground. IUCN and WWF, leaders in the environment, have entered substantively and constructively into the water and food discussion, and now support many activities related to water, food and livelihoods. The Ramsar convention on Wetlands now promotes for example, the wise use of wetlands, recognizing that wetlands can be used for agriculture, but in a sustainable manner. This evolving dialogue, it is hoped, will lead to a balanced construct of eco-agriculture that will meet the needs of societies and ecosystems. Thus while broad developmental goals have affected donors thinking about irrigation investments, a number of other drivers too have been at play. Table 2 captures the evolution of public irrigation policies and drivers based on Barker and Molle, 2004.

Table 2. Evolution of public irrigation since the 1960s.

| Context | 1960s to 1980s | 1990s to present |
|---|---|---|
| Goals and drivers | Food security | Livelihoods, income |
| Resources: land, water and labour | Abundant | Increased scarcity |
| Hydraulic development stages | Construction, utilization | Utilization, allocation |
| Dominant expertise | Hydraulic engineering, agronomy | Multidisciplinary, sociology, economics |
| Irrigation governance | Public | Mixed |
| Irrigation technology | Surface gravity flow | Groundwater, conjunctive, lift based |
| System management | Supply driven | Farmers demand oriented |
| Crops | Cereals and cotton | Diversified |
| Cropping intensity | 1-1.5 | 1.5 – 2.5 |
| Value of water | Low | Increasing |
| Concern for environment | Low | Increasing |

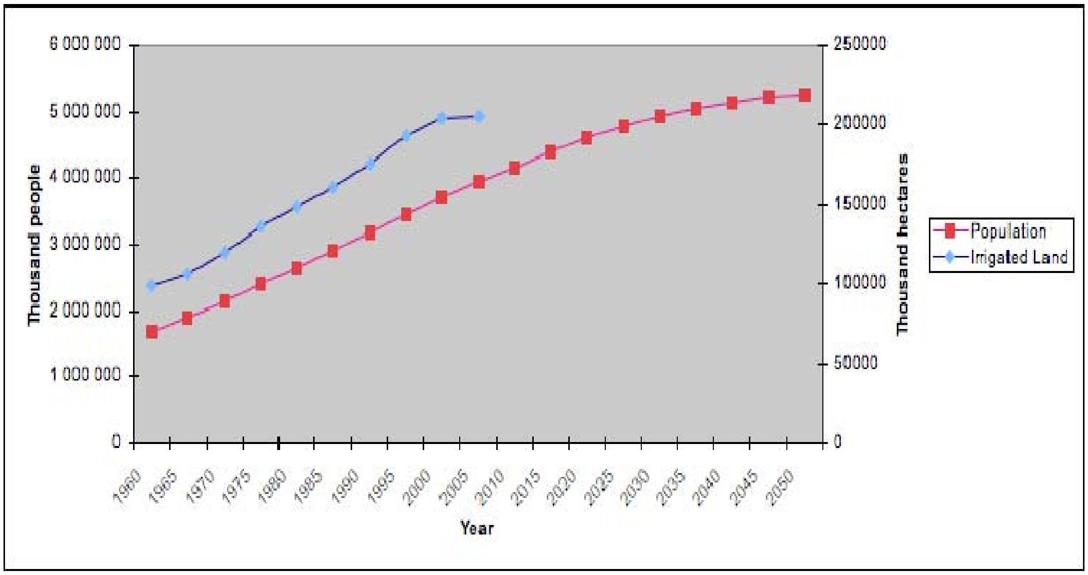
Source: Adapted from Barker and Molle, 2004.

## 2.1 The Malthusian pressures: Rising population, increasing land and water scarcity

Over the latter half of the 20th century, area under irrigation increased in all Asian countries. In 2000, approximately 35 percent of the arable land in Asia was under irrigation, more than half of it was in India and China. However, of late, the rate of growth in irrigated areas has declined substantially (Fig. 2), partly due to lack of donor investments. It is predicted that the only substantial expansion in the future may come from India that plans to create 17.3 million ha of irrigated land by 2020 (ADB 2000).

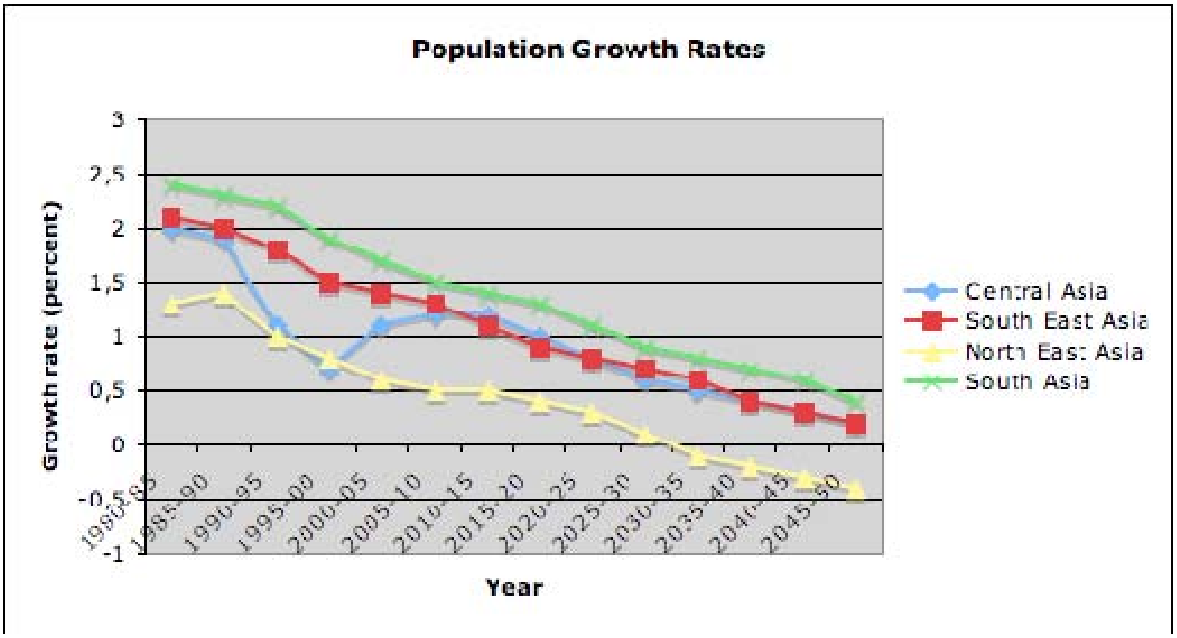
Despite the expansion of agricultural and irrigated lands, per capita land availability in Asia (0.16 ha of person) is lower than world average (0.26 ha per person) (World Resources Institute 2001). Urbanization, industrialization and land degradation means that scope for expansion in agricultural area is limited. For example, expansion of urban and peri-urban areas in China since the late 1970's resulted in an annual loss of 500,000 ha of cultivable land (Rosegrant et al. 2001). Even if the absolute area under cultivation remains unchanged, and population growth rates declined as it is now (Fig. 3), total population in Asia will continue to increase reducing the amount of arable land available per person. Shah (2008) proposes that intensive use of groundwater as it happens in South Asia is a direct response to land scarcity (and not water scarcity, as is often thought) because it provides a scope for intensive cropping.

Figure 2. The evolution of population and irrigated land in Asia



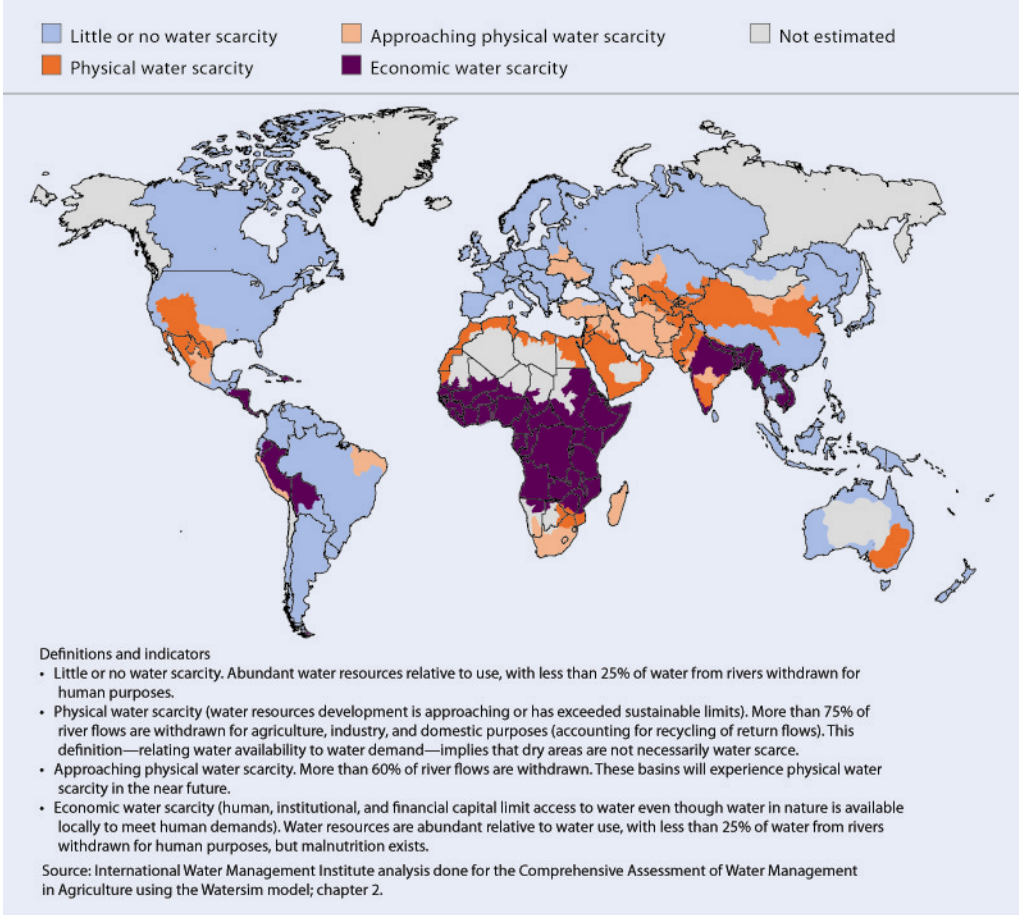
Source: Compiled from data in "World Prospects The 2006 Revision" and FAOSTAT 2008

Figure 3. Population growth rates in Asia



Source: Compiled from data in FAOSTATS

Figure 4. Water scarcity map of the world



Definitions and indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 2.

Source: Comprehensive Assessment of Water Management in Agriculture, 2007

Fig. 4 shows that in much of the arid and semi-arid regions of Asia physical water scarcity already occurs or will occur in the future.[1] In these areas, there is not enough water to meet projected human and environmental demands by 2025. Some parts of South Asia and South East Asia suffer from economic water scarcity. In these regions enough fresh water is available to satisfy projected 2025 demands but water shortages occur due to of the lack of investment in infrastructure and in institutional and human capacity. Physical and economic scarcity will induce different types of pressures, in regions of physical scarcity of water, irrigation needs to be more efficient,

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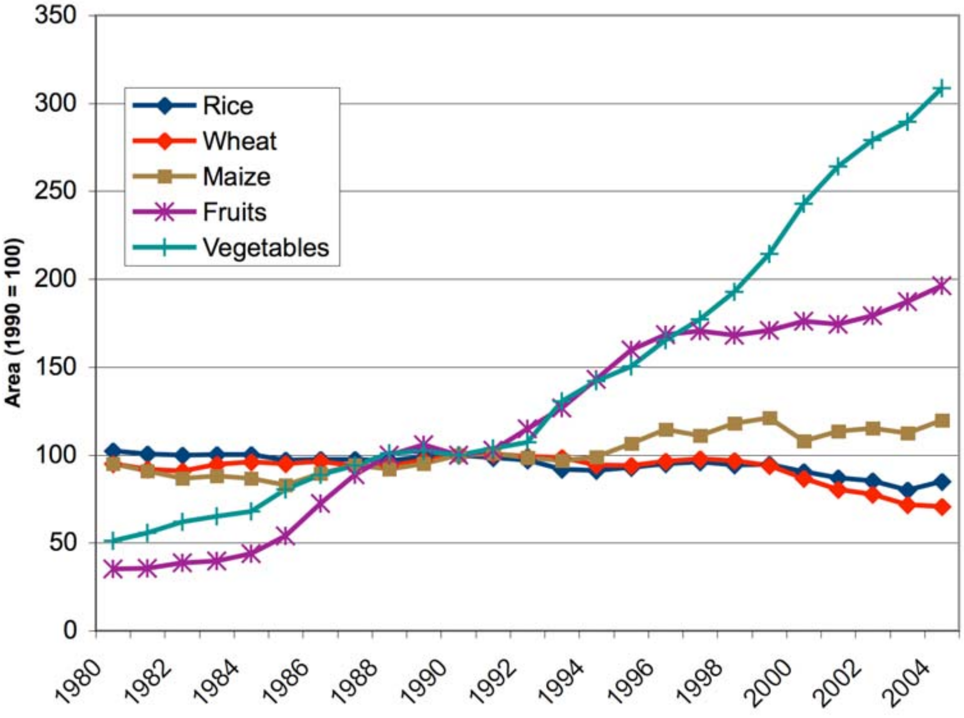
[1] While IWMI classes much of Central Asia as physically water scarce, Varis and Rahaman (2008) note that a closer look at reality reveals that all the countries surpass the water scarcity limit of one thousand m$^3$ per capita. The authors blame the current "sky-high" per capita water use and the enormous environmental problems on the uneconomic and unsustainable agricultural policies that have been put in place since the '60s.

while in regions of economic scarcity, new investments, along with better management practices are needed.

## 2.2 Stagnant cereal productivity and pressure for diversification

While Asian agriculture feel the pressure of both land and water scarcity, what compounds the problem is that productivity gains attained during the early years of Green Revolution are leveling off, creating concerns that unless new breakthroughs in terms of better seeds and land and water management are accomplished, producing enough food to feed the increasing number of people may emerge as a challenge. Increase in food demand and a diversification in diets by a fastly growing urban population bring pressures for a change in domestic agricultural systems from traditional subsistence production to diversified production. In China, for instance, both area and production of fruits and vegetables has been increasing steadily, often at the cost of staple crops like rice (Fig. 5). Diversification is however constrained by a range of physical and economic factors (Barker and Molle 2004; Pingali 2004). The rigid design of surface irrigation projects originally designed to provide extensive irrigation to cereal crops is one such constraint as is the availability of markets and roads.

Figure 5. Production (in 1000 tons) of different crops in China, 1995-2003.



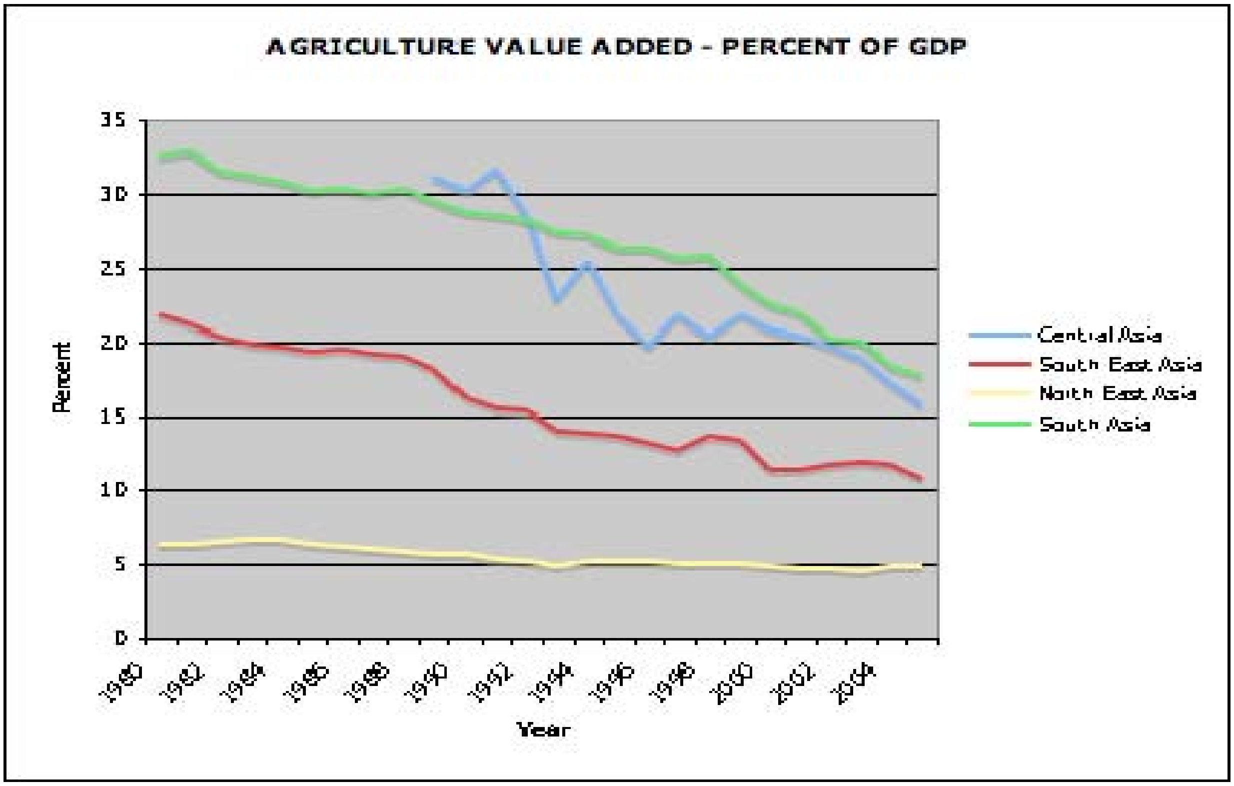
Source: Turral et al. (2008)

## 2.3. Declining contribution of agriculture to GDP

In all regions of Asia, except North East Asia the contribution of value added agriculture to GDP is showing a downward trend (Fig. 6). In developed countries that make up much of

North East Asia most value added production is concentrated in the financial, trade and public services sectors while agriculture production contributes only approximately 5 percent to the country's GDP. In other regions of Asia the share of agriculture is still much higher. The decline in the share of agriculture and the rise of manufacturing and service sectors are associated with the low price and income elasticity of food demands and the rapid diffusion and application of modern technologies. Declining contribution of agricultural GDP often makes it harder to justify new irrigation schemes. At the same time, increasing contribution of other sectors mean that farmers have newer exit options from agricultural livelihoods, one that they did not have 20 to 30 years ago.

Figure 6. Declining trend of agricultural GDP to total GDP



Source: UNEP/DEWA/GRID-Europe, GEO Data Portal, compiled from World Bank, World Development Indicators, 2007

## 2.4 Competing demands for water from other sectors

For Asia as a whole, 86% of the total water withdrawal is for agriculture, eight percent to satisfy the needs of the industry and six percent is for domestic purposes. Trends (Fig. 7) shows that in emerging countries, while the share of water use for agriculture remains high, withdrawals for industrial and domestic purposes are on the rise. Fast paced industrial growth and urbanization, especially in the emerging economies in India and China increases competition for water from the various sectors. In Central Asia the share of agriculture in water use has increased since the early 80's. The increase is most probably due to a combination of factors, such as use of degraded infrastructure that results in high water losses and inefficient management. The relatively large share of the domestic and industrial sectors in water use (compared to use by the agricultural sector) in North East Asia reflects the fact that the higher level is the development, the more water is used for satisfy the needs of those sectors and less water is used for agriculture. There are however some important exceptions. Japan still uses a large share of its freshwater to irrigate rice (Hinrichsen *et al*. 1998).

Figure 7. Water use by sectors, India and China.

According to the IPCC (2001), freshwater use has increased substantially in the natural-economic regions of Asia in recent decades and that trend in increase will continue well into the 21st century. The IPCC (2001) also suggests that water use in most regions of Asia (except for

Southeast Asia) has exceeded by 20 percent the available water resources. The implication is that in the 21st century water is going to be a scarce commodity in much of Asia. Taking into consideration growing needs for water for industries and households, food security for a growing population must be achieved using less water for agriculture (Barker and Molle 2002).

## 2.5 Environmental water demands

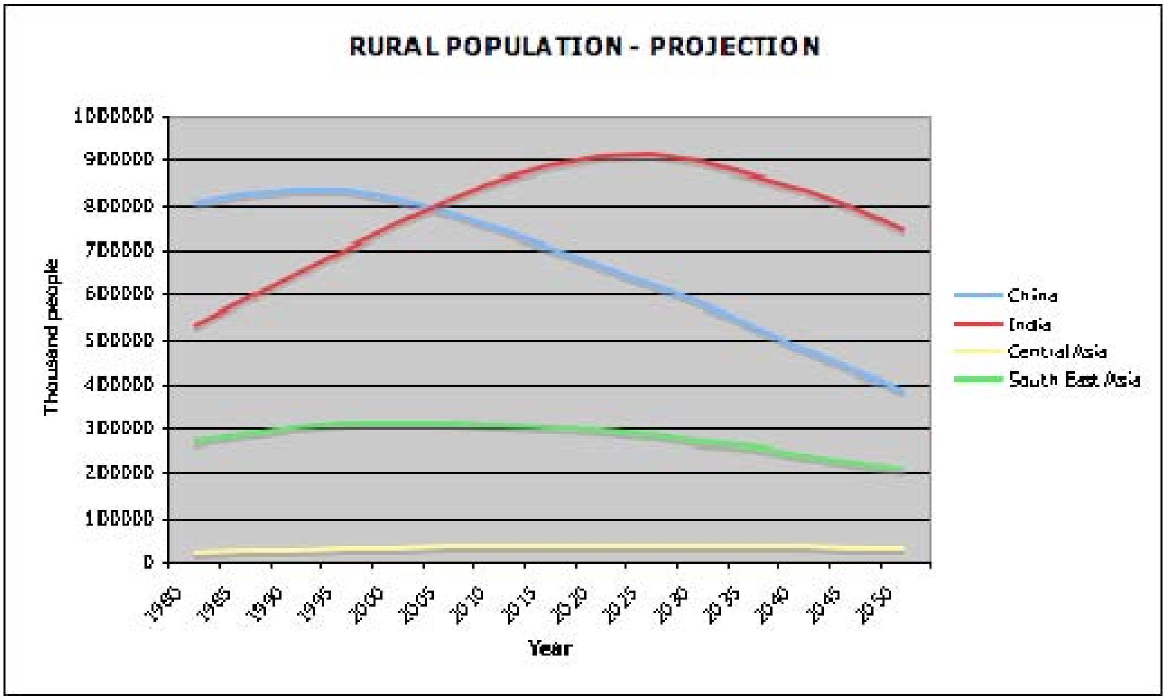
Poorly conceived irrigation infrastructure and management has caused adverse changes in the quality and quantity of water in inland and coastal aquatic and terrestrial ecosystems. Today, excessive withdrawal of water is greatly impacting many of the major river basins of Asia, including the Yellow River, the Aral Sea tributaries and the Ganges and Indus rivers suggesting that the minimum flows that are required for ecosystem health have been over-appropriated (Falkenmark 2007). Due to unsustainable groundwater use in the pump-intensive areas of India and China, water tables are falling at a rate of 1-3 m/year (de Vries *et al.* 2003). Allocating flows for the environment, although a challenge because irrigators must manage with smaller and less dependable allocations for cropping, may become a requirement (i.e. Mekong Agreement) in the long term. Environmental water requirements will increasingly become a driver of change in the future in conjunction with impacts of climate change.

## 2.6 Demographic transition and the “new rurality”

Asia is going through a demographic transition manifested through rapid urbanization and a phenomenon dubbed as “new rurality” by Rauch (2007). New rurality, or the new face of rural poverty and livelihoods stems from globalisation and deregulation and manifests itself through the dynamics of markets. By 2025, 52 percent of the population in East Asia, 53 percent in Southeast Asia and 45 percent in South and Central Asia is projected to be urban. Asia’s rural population is also growing and is predicted to grow, although at a slower rate. Figure 8 shows that in China a reduction in rural population has started in the 90s, a trend that is predicted to continue. India’s the rural population will continue to increase until approximately 2030, after which a marked reduction in the number of people living in rural areas is predicted to occur.

‘New rurality’ manifested through better integration with national and international markets offer both an opportunity and threat to farmers. For one, for the first time in several centuries, farmers in Asia have real opportunity of exiting agricultural sector for better paying jobs and those who are left behind can earn higher incomes through cultivation of ‘niche crops’. Rural people in central locations (close to markets) and having better access to inputs, financial services and information) are better able to take advantage of opportunities provided by new demands than people living in remote areas and on limited resources. But in both cases rural livelihoods are becoming increasingly diversified, mobile and multilocal (Faurès and Santini 2008) and hence irrigation interventions need enough flexibility to cater to these changing realities.

Figure 8. Evolution of rural population in selected countries and regions in Asia



Source: UNEP/DEWA/GRID-Europe, GEO Data Portal, compiled from UN Population Division, World Urbanization Prospects: The 2007 Revision

## 2.7 Rising standards of living and changing diets

A growing and wealthier population requires more food per person and a rich and varied diet (Molden *et al*. 2007). In Asia, beside the rising per capita consumption, dietary changes are reflected by a move away from a diet dominated by cereal crops to one dominated by fruits, vegetables milk and animal protein (Fig. 9.1 and 9.2). The transition is most noticeable in cities and smaller towns especially in East and in Southeast Asia and is expressed by declining consumption of rice, by a growth in per capita wheat consumption and by a growth in demand for temperate zone vegetables and fruits, meat and dairy products (Pingali 2004). In China over the last 20 years meat consumption has more than doubled and it is projected to double again by 2030. Increasing consumption of fruits and vegetables means increasing production of the same and these have different irrigation requirements than cereal crops. The implications of those developments in terms of arable land and water needs are important, as milk and meat and vegetable products require more land (in the case of meat and milk) and water (in the case of milk, meat and vegetables) to produce (Molden, 2007).

Figure 9.1. Per capita meat supply versus income in India (pink), China (green) and USA (black) over the period 1961-2003

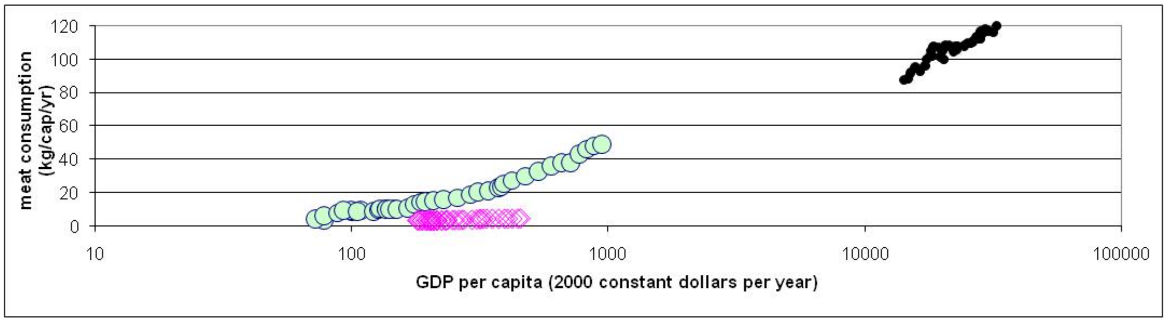
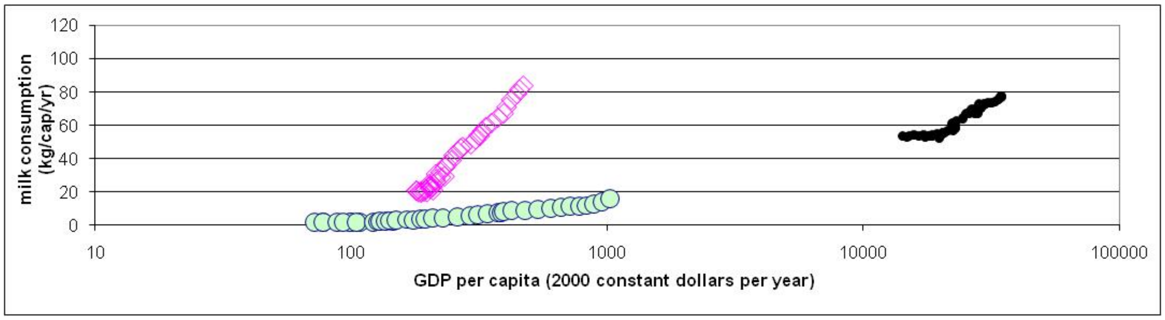


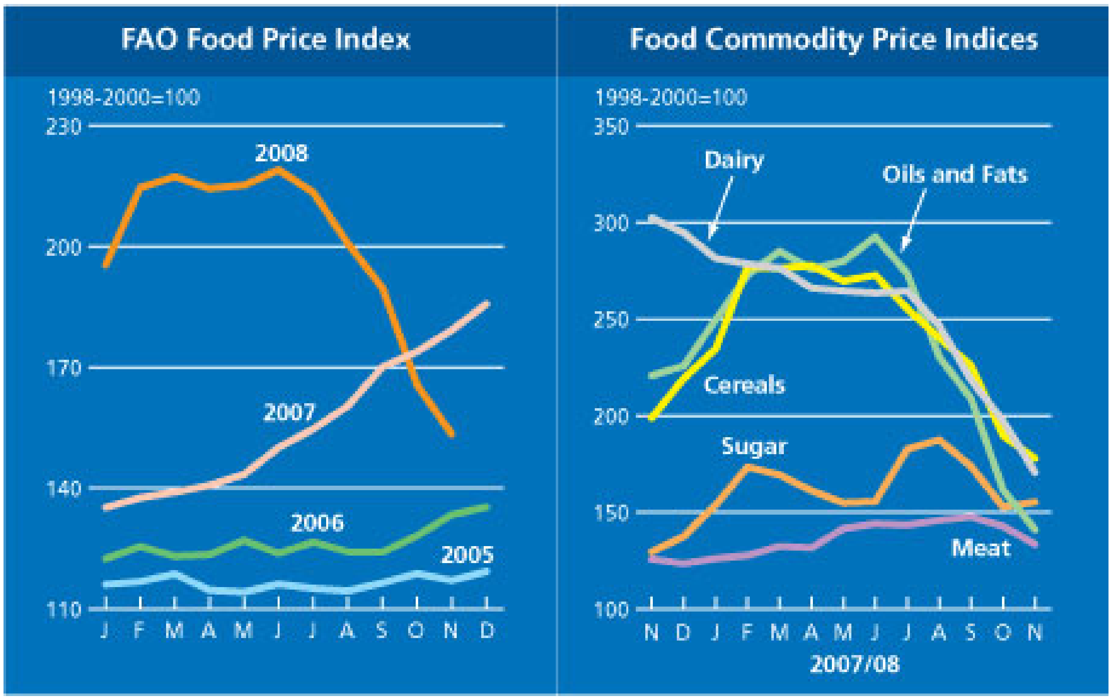
Figure 9.2 Per capita milk supply versus income in India (pink), China (green) and USA (black) over the period 1961-2003



## 2.8 Food prices

Much of Asia's irrigated land is devoted to production of food crops. Except for a steep spike in 2007-08, cereal prices have been going down in real terms since mid 1970s (see Fig. 1). The reasons for the decline in grain prices were unprecedented increase in grain production as a result of the expansion of irrigated areas; the decline in demand of cereal grains as incomes rose and diets changed; and to a large extent, subsidies provided by developed economies. Since then, consumers, including millions of poor rural households, enjoyed relatively low staple food prices. Another consequence of low grain prices was that profits from grain production have shrunk encouraging Asian households to diversify agricultural production and livelihoods (Barker and Molle 2004). That declining trend was reversed by a sudden and dramatic increase in world food prices in 2007-2008 causing wide spread panic. The increase is attributed factors such as the declining dollar, rising energy prices, an increase in biofuel production, (IFPRI, 2008) increased demand for wheat, meat, milk, oil, food and vegetable produce and an underinvestment in research and technology and rural infrastructure, especially irrigation. However, this spike was short lived and prices of food grains fell below 2007 prices (Fig. 10). Nonetheless, it is widely believed that there will be an upward shift in the food prices (IFPRI, 2008). Food prices directly impact cropping decisions of the farmers and hence their irrigation requirements.

Figure 10. Food price index (FAO, 2008)



Downloaded from http://www.fao.org/worldfoodsituation/FoodPricesIndex/en/

## 2.9 National food and energy policies

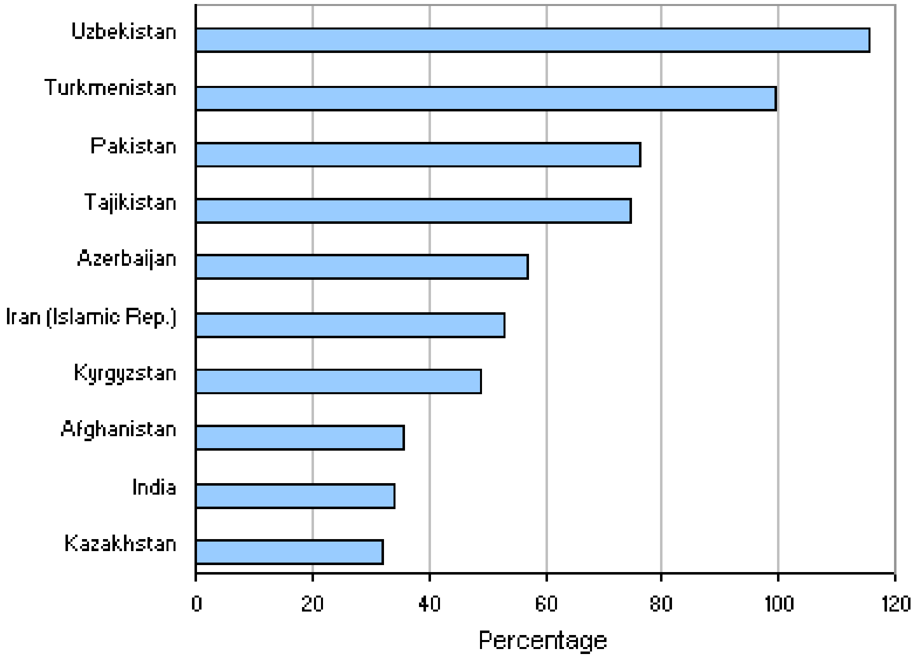
Energy and food policies are closely interlinked. Recent increases in food prices were partially blamed on the high energy prices and the "energy-irrigation nexus" received wide attention. Energy prices affect agricultural production in two ways, one, by increasing the costs of inputs (e.g. fertilizer, pumping costs if using diesel pumpsets etc.) and also the cost of transportation of agricultural produce to the market. One on the other hand, food prices had remained stagnant for a long time, thereby squeezing farmers' profits. This "energy squeeze" was particularly pronounced in eastern India and Bangladesh who depend overwhelmingly on diesel operated pumps (Shah 2007, Mukherji, 2007). In response, farmers in South Asia shifted away from staple crops like paddy towards vegetables and other higher value crops. In recent times, high fossil fuel prices have started impacting agricultural production in a third and perhaps more important way than ever, through demand for bio fuels. For instance, the USA, one of the largest producers of corn, has diverted substantial quantities of corn to bio-fuel production. This was a result of the US government's debatable policy of substituting fossil fuel with bio-fuel as a means of mitigating climate change impacts. In Asia, sugarcane is seen as a viable crop for producing bio-ethanol, but this might have livelihoods implications as sugarcane is a land intensive and labor extensive crop, not particularly suited to regions with surplus labor. Food polices, especially national food pricing and subsidy policies affect cropping decisions by distorting incentive structure. An apt example of such distortion is the water intensive rice-wheat cropping pattern in water scarce Pakistan and Indian Punjab.

## 2.10 International trade policies and politics

Multilateral trade agreements such as GATT have potentially profound influence on agricultural production in developing countries and hence most Asian countries, including India and China have taken cautious steps towards liberalization of agricultural trade because of fears from rising agricultural prices for small food-importing economies and adverse effects on food security and poverty (UNESCAP 2008). However, in the future, chances are barriers to trade would have to eased, both by the developed as well as the developing countries and this would certainly drive changes in the agricultural sector.

Dismantling of the former Soviet Union in 1991 was an important driver of change in irrigation, especially in Central Asia. In the landlocked Central Asian region endowed with arid and semi-arid climates, where much of the countries' agricultural lands are located, the Soviet Union developed one of the largest irrigation themes in the world. Today, approximately 22 million people depend, directly or indirectly, on irrigated agriculture (Bucknall *et al.* 2003). Due to the neglect of infrastructure by the independent governments in the post Soviet era irrigation infrastructure has greatly deteriorated, while at the same time, wasteful use of irrigation water continues (Fig. 11).

Figure 11. Proportion of water withdrawn to total renewable water, 1998-200



## 3. Impacts of irrigation interventions

As already mentioned, starting with the late 1960's, Asian agricultural economies have been experiencing significant upswings in productivity. As widely acknowledged, Green Revolution, was made possible through well coordinated infusions of vital inputs into the agricultural systems of the region. Irrigation through major and medium canal systems and later groundwater use (in south Asia particularly) was the most crucial input to the Green Revolution. In this section of the paper, we draw upon the lessons derived from IWMI-ADB study on impacts of irrigation impacts in selected Asian countries (Hussain, 2005; IWMI, 2007).

### 3.1 Typology of benefits and costs of irrigation

Irrigation affects various facets of socio-economic and other systems in its context. The nature of the impact on each system varies and comprises a complex web of benefits and costs. Based on the country studies, the impact of irrigation systems has been generalised into five generic typologies as shown in Table 3.

Table 3. Typology of irrigation benefits and costs.

| Type | Benefits | Cost |
|---|---|---|
| Type 1 | Direct benefit from employment generation | Direct cost of displacement of the poor households and potential for land encroachment |
| Type 2 | Direct benefit from increase in crop productivity | Direct cost of land degradation through salinity and over-use of chemical fertilisers |
| Type 3 | Localised indirect benefits from productivity induced employment, wages, income and consumption | Localised indirect cost of unemployment through land degradation, mechanisation and other labour saving technologies |
| Type 4 | Other localised benefits from multiple usage of water, groundwater recharge and private investment in irrigated agriculture | Other localised costs of public health risks, loss of biodiversity and water pollution |
| Type 5 | Broader level multiplier benefits from linkages with non-agricultural sectors | Broader level costs of abstraction of river waters leading to degeneration of river health and consequent impact on livelihoods of poor communities dependent upon river health. |

Source: IWMI, 2007

The IWMI- ADB study found that irrigation reduced poverty significantly and that incidence of poverty in irrigated areas were only half as much as in non-irrigated areas. It is recognized that there are at least three pathways through which benefits from irrigation translates into poverty reduction. These are:

(i) Micro-pathway: increasing returns to the physical, human and social capital of the poor.
(ii) Meso-pathway: integrating the poor with factor, product and information markets.
(iii) Macro-pathway: improving national growth rates and creating second generation positive externalities.

However, two important qualifiers remain. Firstly, though incidence of poverty gets reduced through irrigation, it does not get obliterated. The average incidence of poverty in irrigated areas is still 34 percent. Further, significant inter-country, inter-region, inter-system and even intra-system differences are observed in the incidence of poverty. Table 4 gives a snapshot of these differences.

Table 4. Illustration of types of differences in incidence of poverty

| | |
|---|---|
| Inter-country difference | Observed incidences of poverty in the studied systems are as follows: China (7%), Vietnam (15%), India (40%), Indonesia (41%), Bangladesh (47%) and Pakistan (52%) |
| Inter-regional difference | Southeast Asian and Chinese systems show less poverty incidence than South Asian systems. |
| Inter-system difference | Net productivity benefits (difference in net output values between irrigated and non-irrigated areas) ranges from less than \$50/hectare/year in Hakra-4 (Pakistan) to over \$600/hectare/year in LID-HP (Henan, China) |
| Intra-system difference | Significant differences exist in incidence of poverty among the upper, middle and tail reaches of irrigation systems. Again, this differs across countries. The largest disparities are observed in India while Chinese systems are the most equitable. |

Source. IWMI 2007

While benefits derived from irrigated agriculture are undeniable, of late, the costs incurred, especially the cost in terms of ecological impacts have become increasingly important. For instance, it is often the case that irrigation development upstream affects biodiversity (especially natural fisheries) downstream (Attapatu & Kodituwakku 2008). Water logging, soil salinization, decline in groundwater tables are some of the other easily recognizable, but hard to solve negative impacts of irrigation.

## 4. Future scenarios of water and food in Asia: An application of WATERSIM model

### 4.1 Major pathways to meet future food demand

The policies and investment strategies chosen to increase food production will affect water use, the environment, and rural and urban poverty. Feeding 1.5 billion more Asian people by 2050 will require water development and management decisions that address tradeoffs between food and environmental security. Four broad strategies include (Fraiture et al 2007):

a) Investments to increase production in **rainfed agriculture**- improving productivity through enhanced management of soil moisture and supplemental irrigation if small water storages are feasible; expanding cropped areas
b) Investments in **irrigated agriculture**: increasing annual irrigation water supplies by innovations in system management, developing new surface water storage facilities, and increasing groundwater withdrawals and the use of waste water; and increasing water productivity in irrigated areas and value per unit of water

by integrating multiple uses—including livestock, fisheries, and domestic use—in irrigated systems.

c) **Agricultural trade** – by trading agricultural products from water rich and highly productive areas to water short areas.
d) Reducing gross **food demand**—by influencing diets, and reducing post harvest losses including industrial and household wastes.

Each of these strategies will affect water use, the environment, and the poor in different ways. Enhanced agricultural production from rain fed areas and higher water productivity on irrigated areas can offset the need for the development of additional water resources (Molden et al 2007; Rosegrant et al. 2002, Rockstrom et al. 2003). But the potential of rainfed agriculture and the scope to improve water productivity in irrigated areas is debated (Seckler et al 2000, Rosegrant et al 2002, Kijne et al. 2003). Trade can help mitigate water scarcity if water-short countries import food from water abundant countries (Hoekstra and Hung 2005). But political and economic factors may limit its scope (Fraiture et al, 2004, Wichelns 2004). Investments in irrigated agriculture will help alleviate rural poverty (Castillo et al 2007, Faures et al 2007). But irrigated area expansion may have serious consequences for the environment (Falkenmark et al 2007). Reducing losses that occur in the food chain (i.e. from farmers' field to consumers' plate) will help reduce food demand and hence reduce water used in agriculture but because of the high number of actors involved improving the efficiency in the food chain may prove challenging (Lundqvist et al 2008). Views on what future pathways are most appropriate diverge strongly.

## 4.2 Future pathways

We use scenarios to illustrate and quantify tradeoffs in investment strategies using the WATERSIM model (Fraiture 2007). This numerical model consists of two fully integrated modules: a food production and demand module based on a partial equilibrium model, and a water supply and demand module based on a water balance and accounting framework. To adequately capture both hydrologic processes at basin scale and economic phenomena at country scale, the model uses 282 hybrid units intersecting 128 hydrological units with 115 socio-economic units (i.e. countries and country groups). The scope and feasibility of productivity enhancement and area expansion vary by region. Regional variation of opportunities and limitations are incorporated in the scenario analysis. For the purpose of this paper results are aggregated into South and East Asia.

Productivity growth is modeled as function of the exploitable yield gap, i.e. the difference between maximum attainable and the actually achieved yields. Under an optimistic scenario 80% of the yield gap is bridged; under a pessimistic scenario only 20%. In areas where the yield gap is large productivity growth rates are relatively high. In areas where yields are already close to the maximum obtainable level growth rates level off. The maximum obtainable yields are derived from the Global Agro Ecological Zones (GAEZ) methodology (Fischer et al. 2002; Bruinsma 2003). This methodology uses physical and crop management factors to establish maximum levels of productivity on a grid-cell basis. The maximum attainable yield assumes high input levels and best suitable varieties, depending on the quality of land. This approach provides realistic estimates based on known techniques, without assuming major breakthroughs. The potential of area expansion is determined by GAEZ land suitability classes.

We assume that expansion is limited to lands in classes 'suitable' and 'very suitable' for agriculture.

Scenario analysis conducted as part of the Comprehensive Assessment indicates that growth in water diversions to agriculture varies anywhere between 10% to 57% by 2050 for South Asia and between 16% and 70% for East Asia depending on assumptions on trade, water use efficiency, area expansion and productivity growth in rainfed and irrigated agriculture (Fraiture et al., 2007). Increases in cropped area vary between 3% and 18% for South Asia and 10% and 34% for East Asia. Increases in crop water depletion between 13% and 36% for South Asia and 10% and 43% for East Asia (Figures 12a and 12b).

Figure 12a: Scenarios in South Asia (water and land requirements)

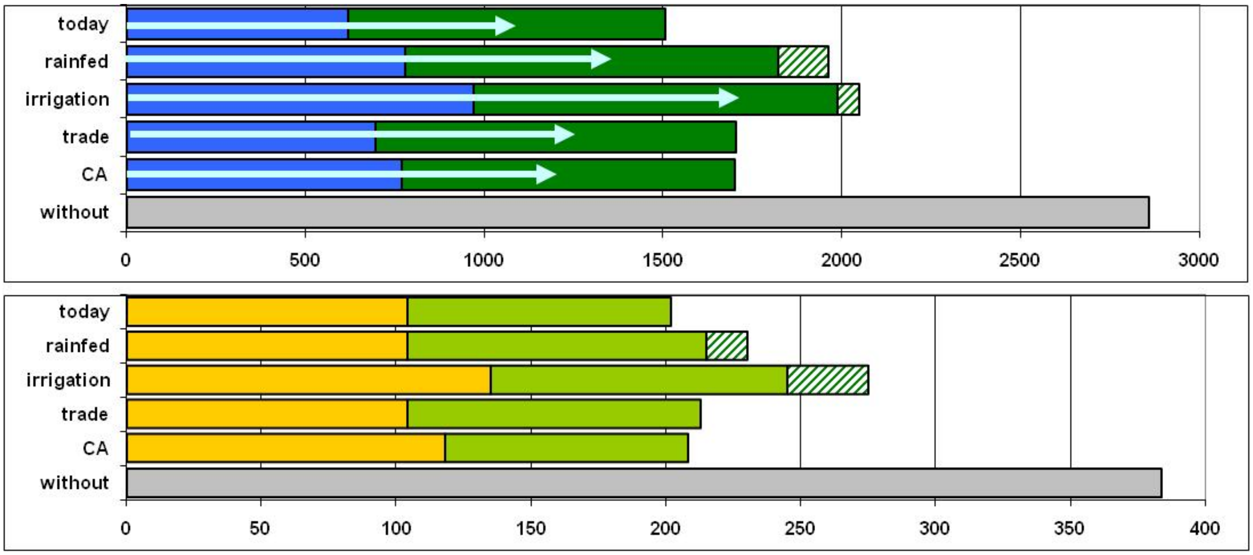
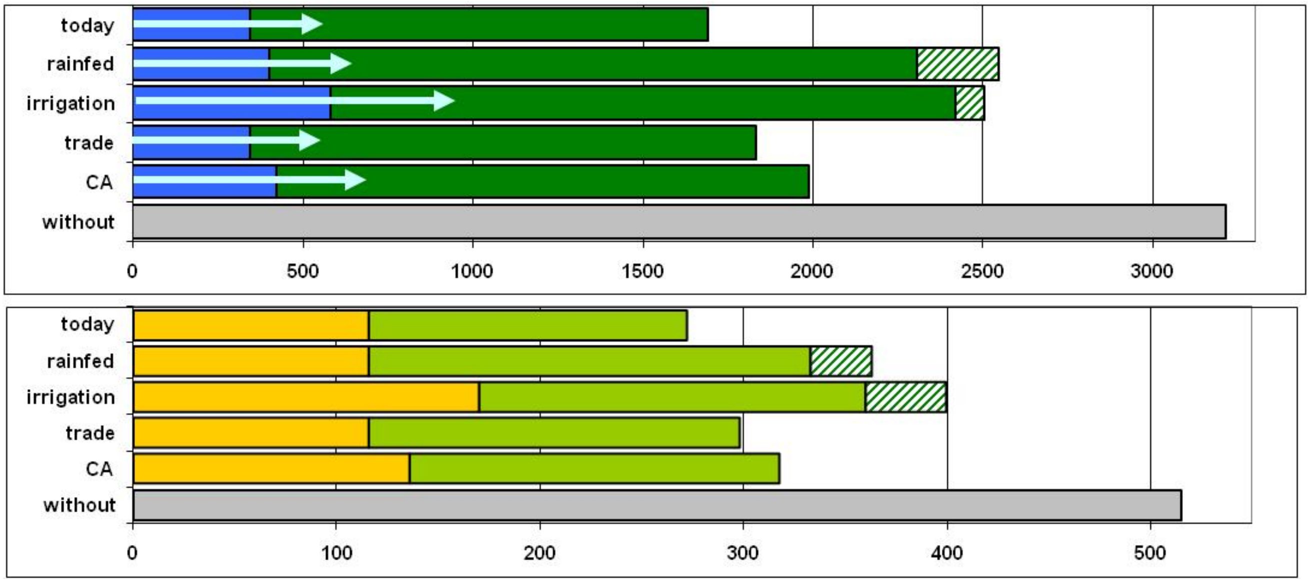


Figure 12b: scenarios in East Asia (water and land requirements)



### 4.2.1 The potential role of rainfed agriculture

Rainfed agriculture plays an important role in today's food supply of East Asia. Just over 50% of the gross value of East Asia's food is produced under rainfed conditions on 60% the harvested land. In South Asia less than one fourth of the gross value comes from rainfed areas consisting of 45% of the harvested area. The productivity gap between irrigated and rainfed areas in South Asia is much larger than in East Asia, pointing to a considerable scope for productivity improvements. However, the future food production that could and should come from rainfed or irrigated agriculture is the subject of debate.

To contrast optimistic and pessimistic views on the potential of rainfed agriculture and assess risks, we develop two rainfed scenarios (Fraiture et al. 2007). A high yield scenario assumes that prices and incentives are right and physical and institutional arrangements are in place (markets, roads, extension services and credit facilities). Under this scenario 80% of the yield gap will be bridged. A low yield scenario assumes that adoption rates of water harvesting measures and supplemental irrigation are low. Under this scenario only 20% of the yield gap will be bridged. The scenario analysis shows that upgraded rainfed agriculture can produce the food required in future (table 5), but there are conditions that must be met.

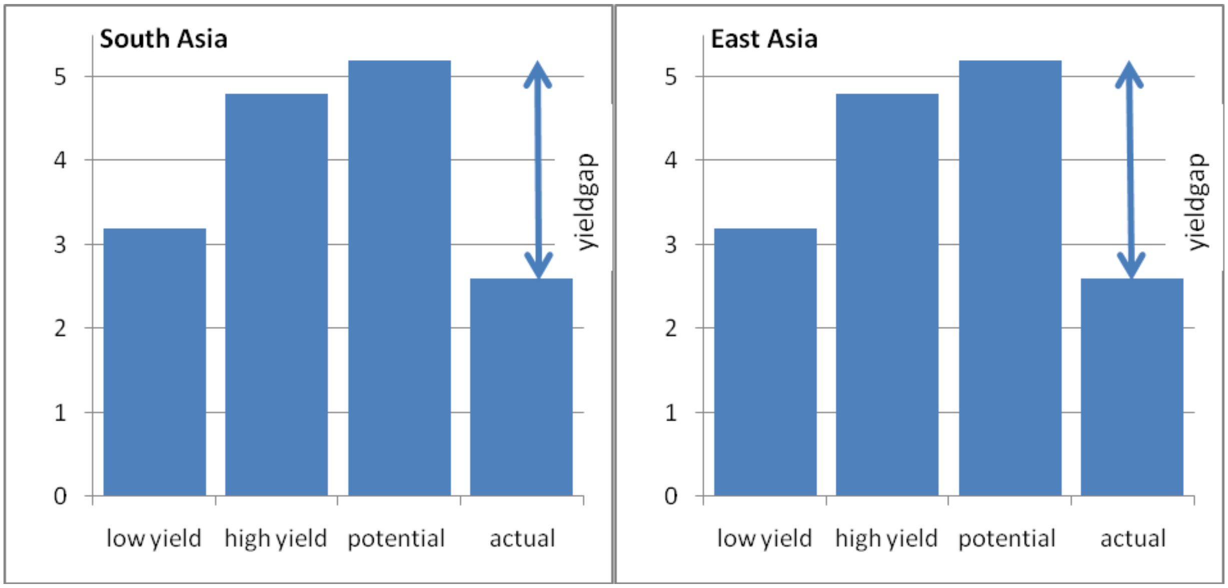
Table 5. Results of optimistic and pessimistic rainfed scenario

| | South Asia | | | | | East Asia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2050 optimistic | growth % | 2050 pessimistic | growth % | 2000 | 2050 optimistic | % growth | 2050 pessimistic | % growth |
| Rainfed cereal yield (t/ha) | 1.4 | 2.9 | 107% | 1.9 | 107% | 2.6 | 4.8 | 85% | 3.2 | 23% |
| Rainfed area (million ha) | 98 | 111 | 13% | 126 | 29% | 156 | 217 | 39% | 244 | 56% |
| Net cereal trade (% of demand)* | 7% | 1% | | -18% | | -5% | -1% | | -19% | |

* Negative numbers signify imports

In South Asia where actual yields are low the yield gap --and hence the potential for growth-- is higher than in East Asia. Under the optimistic scenario rainfed cereal yields more than double from 1.4 tons/ha now to 2.9 tons/ha in 2050 in South Asia but in East Asia the growth is slightly more modest (in relative terms) from 2.6 to 4.8 ton/ha (figure 13). Under the optimistic scenario an increase of 13% of the rainfed area would be sufficient to meet all additional cereal demand in South Asia by 2050. In East Asia the area would have to increase by 39% because of the higher cereal demand for feed and slower yield growth.

Figure 13: Rainfed cereal yields: optimistic and pessimistic scenario, in South and East Asia



Under the pessimistic scenario where rainfed cereal yields only grow by 23% and 39% in South and East Africa respectively, the shortfall in food supply will have to come from an expansion of the area. But where land suitable for agriculture is not available food imports are needed. In South Asia where 94% of the area suitable for agriculture is already is cultivated the scope for expansion is limited (FAO 2002) unless marginal lands are taken into production. Under the pessimistic scenario South and East Asia need to import nearly one fifth of its cereal demand.

Experience indicates that the required productivity increases will not occur without substantial investments in water harvesting, agricultural research, supporting institutions and rural infrastructure. In addition, crop yields will vary with economic incentives and crop prices, as farmers will respond to those parameters when choosing key inputs. A high yield scenario will evolve only if generating high yields is profitable for farmers (Bruinsma 2003). The optimistic scenario assumes appropriate incentives are in place. By contrast, the pessimistic scenario shows that when these are missing more land will be needed. A large expansion of agricultural land may have a negative impact on biodiversity and ecosystem services. Where the scope of area expansion is limited large imports are needed. This may raise political and socio-economic issues.

### 4.2.2 The potential role of irrigated agriculture

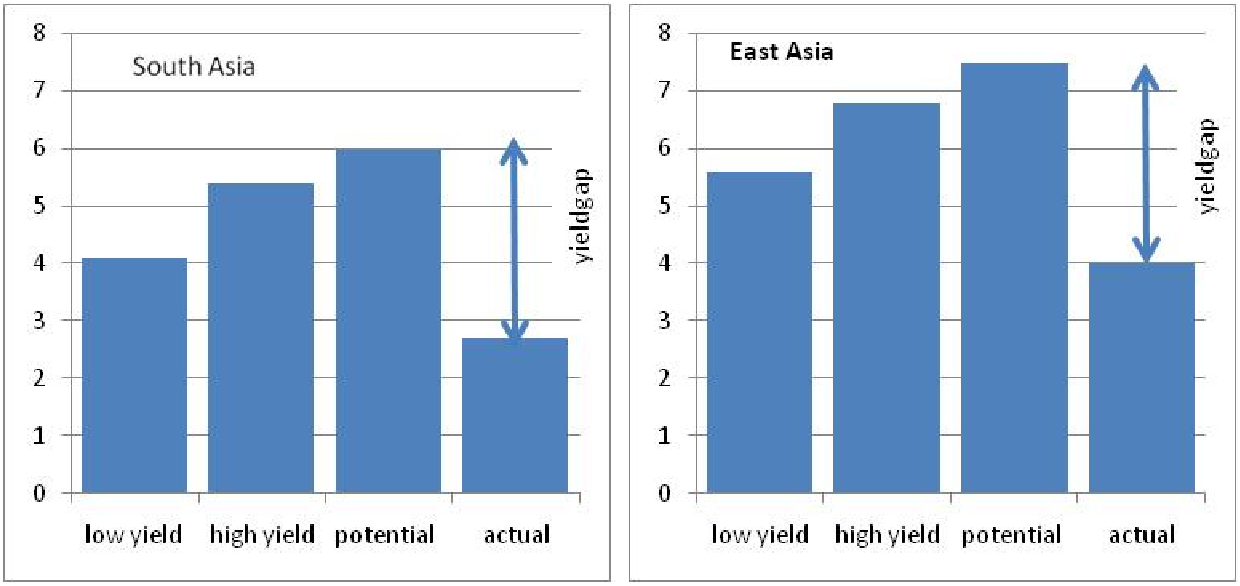
Irrigation plays a major role in food production, while also providing livelihoods to millions of poor farmers in developing countries. Irrigated agriculture currently provides 40% of the global cereal supply. In South and East Asia this is 64% and 68% respectively. East Asia produces close to 60% of the global rice supply, South Asia another 30%,. Total Asia produces 90% of global rice production, mostly under irrigated conditions. With growing food demand

and climate change induced rainfall variability many expect that the contribution of irrigated agriculture to food production and rural development will increase in the coming decades (Bruinsma 2003, Seckler et al. 2000). The perception on costs and benefits of irrigation changed markedly over the past 50 years (CA 2007, Faures et al 2007). After a decade of decline, the last few years have seen an increasing interest in public funding in water infrastructure for agriculture due to concerns of climate change induced rainfall variability; maintaining the existing infrastructure; potential for poverty alleviation; the high potential to improve performance (Faures et al. 2007) and the recent surge in food prices.

Here we contrast two scenarios: one with emphasis on area expansion, the other focusing on yield improvements. The area expansion scenario emphasizes food self-sufficiency and access to agricultural water to more people. Assuming a continuation of the groundwater boom, under this scenario the irrigated harvested area in South Asia grows by 30% over 50 years. In East Asia the harvested area under irrigation increases by 47%. Irrigated yields follow historical trends and grow by 40% and 51% in East and South Asia respectively. With this area expansion South and East Asia can be largely food self-sufficient in 2050, but it would come with a high environmental costs.

Yield improvement scenario explores the gains from enhancing the output per unit of water in irrigated areas. Under this scenario 80% of the gap between actual and obtainable irrigated cereal yield is bridged leading to a doubling in yield in South Asia (from 2.7 to 5.4 tons/ha) and a 70% increase in East Asia (from 4.0 to 6.8 tons/ha) (Figure 14).

Figure 14: Irrigated cereal yields under different irrigation scenarios



Water productivity also substantially improves under this scenario (water productivity of irrigated wheat increases by 41% and 30% respectively) but to a lesser degree than outputs per unit of land. This scenario foresees a 12% and 4% expansion of irrigated area in South and East Asia respectively, while irrigation diversions increase by 29% and 26%. To achieve the improvements in irrigated yields depicted in this scenario, water supplies must be increased in existing irrigated areas. Better timing of water deliveries also is helpful in improving crop yields. All of these measures lead to more water evaporated by crops, a precondition for increasing yields. As a result, water consumption and irrigation diversions increase substantially in this scenario.

The scenario results show the enormous potential of improving performance in existing irrigated areas, particularly in South where more than 50% of the harvested area is irrigated and yields are low. Three quarters of the additional food supply by 2050 can be met by improving productivity of existing irrigated areas (table 6). In South-Asia all additional cereal demand can be met through irrigated yield improvements, though this would require additional water withdrawals. Improving irrigation performance and increasing water productivity is by no means easy (Molden, forthcoming). It requires that the right incentives and policies are in place to induce farmers to increase water productivity. Arguably, the largest gains in water productivity in value per unit of water are achieved by diversification and by using water for many productive purposes—such as fisheries, livestock, home gardens, and other small enterprises (van Koppen, Moriarty, and Boelee 2006). This may require changes in irrigation design to incorporate small dams, fisheries, and flood protection.

Table 6. Results of irrigated yield improvement and area expansion scenario

| | South Asia | | | | | East Asia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2050 yield scenario | growth % | 2050 area scenario | growth % | 2000 | 2050 yield scenario | % growth | 2050 area scenario | % growth |
| irrigated cereal yield (t/ha) | 2.7 | 5.4 | 100% | 4.1 | 52% | 4.0 | 6.8 | 70% | 5.6 | 40% |
| irrigated area (million ha) | 104 | 115 | 11% | 135 | 30% | 116 | 121 | 4% | 170 | 47% |
| Net cereal trade (% of demand)* | 7% | 0% | | 2% | | -5% | -6% | | -4% | |

* Negative numbers signify imports

### 4.2.3 The role of trade: virtual water, can it work in reality?

Because the production of agricultural commodities requires large quantities of water, expanded international food trade can have significant impact on water demands at the national level. Allan (1998) coined the term 'virtual water' to denote the water used to produce crops that are traded internationally. By importing agricultural commodities, a nation 'saves' the amount of water it would have required to produce those commodities in country (Hoekstra and Hung 2005). At the global level, cereal trade has a moderating impact on irrigation water demand, as four of the five major grain exporters (USA, Canada, France, Australia and Argentina) produce grain in highly productive rainfed conditions. Major importers, such as Egypt, Mexico, Iran, Saudi Arabia, and Algeria, rely on irrigation to produce grains. In 1995 without cereal trade global irrigation water demand would have been higher by 11% (Fraiture et al 2004, Oki et al 2003).

International food trade could thus contribute to mitigating water scarcity problems. To assess the potential of trade as water saving mechanism we formulate the 'ideal virtual trade' scenario in which countries with abundant water resources and production capacities increase their agricultural production and export to water-short countries. North America, Latin America (mainly Brazil and Argentina), Northwest Europe, and Eastern Europe (Russia and Ukraine) export to the Middle East and North Africa and to India, Pakistan, and China. In the importing countries, crop yields improve at a modest pace (25%) while irrigated and rainfed areas remain constant. Water-short areas in China, India, the Middle East and North Africa reduce their irrigated areas for cereals, shifting toward labor intensive, higher valued crops such as vegetables. In exporting countries rainfed yields of staple crops—such as cereals, soybeans (oil crops), and roots and tubers—improve by 60% on average. Rainfed areas in exporting countries increase by 260 million hectares, primarily in Latin America, where the scope for area expansion is still large.

The scenario analysis reveals that, in theory, world food demands can be satisfied through international trade, without worsening water scarcity or requiring additional irrigation infrastructure (de Fraiture et al 2007). But this would mean a considerable increase in food imports in both South and East Asia to around one fourth of the cereal demand by 2050 (table 7).

Table 7. Trade scenario results

| | Cereal demand 2000 (million metric tons) | Net cereal trade 2000* (million metric tons) | Net cereal trade 2050 (million metric tons) | Net trade as percentage of demand 2000 (%) | Net trade as percentage of demand 2050 (%) | Increase in Irrigation withdrawals |
|---|---|---|---|---|---|---|
| Global | 1840 | 2880 | 145* | 8% | 17% | 5% |
| South Asia | 241 | 16 | -119 | -7% | -25% | 10% |
| East Asia | 505 | -25 | -191 | -5% | -24% | 1% |

For many years, the Indian government has focused on achieving national food self-sufficiency in staples. With extensive investments in agriculture (mainly large scale public irrigation schemes and small scale private tubewells) India became food self-sufficient in main staples and has been a net exporter of food over the past few years. More recently, as the imminent danger of famines has decreased and non-agricultural sectors have expanded, the national perspective regarding production and trade has changed. Food trade might become more important in future, particularly as the relative contribution of non-farm sectors increases in the Indian economy. (Dasgupta and Singh 2005; Rigg 2005).

But because of socio-economic and political reasons it seems unlikely that water concerns will be a main driver of increased trade volumes in the near term. Low income countries struggling with food security remain wary of depending on imports to satisfy basic food needs. Food imports must be paid for with foreign exchange which is earned by selling exports or obtained through grants and loans (Seckler et al. 2000). Many poor countries do not have sufficient exports to pay for imports, and recent hikes in food and energy prices further worsened the trade balance of many importers. Trade requires substantial amounts of energy for transporting goods, adding to the financial and environmental costs of trade. Fluctuating prices and dependence on one or few export commodities make poor countries particularly vulnerable. A degree of food self-sufficiency -and the development of water resources to achieve this- therefore still is an important policy goal. This was acutely illustrated in the first half of 2008 when rice, wheat and maize prices soared. Main exporters such as Viet Nam, Thailand and India responded by restricting rice exports over concerns of national food supply. In order to make use of agricultural potential elsewhere without relying on trade some countries recently started buying or leasing large tracts of agricultural land, primarily in Sub-Saharan Africa. The implication is that under the present global and national geopolitical situation, it is unlikely that trade alone will solve water scarcity.

### 4.3 How much more irrigation do we need? An optimistic scenario

Optimal strategies for meeting future food and water demands differ by region (table 8). In South Asia, 60% of the harvested area is irrigated and the gap between obtainable and achieved yield is large. The scope to augment food supply and raise rural incomes by improving yields is high. By contrast in much of East Asia yields are already high and net imports are expected to rise to meet future food demands.

We formulate an optimistic scenario combining positive elements from the scenarios above and accounting for the regional opportunities and constraints. Broadly speaking this scenario entails emphasis on irrigation performance improvements in South Asia, with modest area expansion. Where groundwater overdraft takes place areas under irrigation are reduced. In East Asia, both irrigated and rainfed yields are improved, but because of the relative limited scope and higher projected food demand East Asia net food imports will increase. Globally rainfed yields increase by 58% and irrigated yields by 55%. This scenario shows that even under optimistic assumptions related to productivity growth crop water consumption increases by 20% while withdrawals to agriculture increase by 13% by 2050. For South and East Asia irrigation withdrawals increase by 9% and 16% respectively.

Table 8: An optimistic scenario, results

| | Irrigated water productivity cereals 2050 (kg/m$^3$) | Cumulative change (%) | Rainfed water prod. cereals 2050 (kg/m$^3$) | Cum. change (%) | Crop water consumption 2050 (billion m$^3$) | Cum. change (%) | Irrigation withdrawals 2050 (billion m$^3$) | Cumulative change (%) |
|---|---|---|---|---|---|---|---|---|
| South Asia | 0.79 | 62 | 0.46 | 82 | 1700 | 15 | 1195 | 9 |
| East Asia | 1.06 | 45 | 0.57 | 36 | 1990 | 19 | 601 | 16 |
| World | 0.93 | 38 | 0.64 | 31 | 8515 | 20 | 2975 | 13 |

The scenario analysis makes clear that water use will increase as food demand rises. Even under optimistic assumptions this will likely lead to increases in crop water requirements and irrigation withdrawals. The challenge is to manage this increase in a way that minimizes adverse impacts on ecosystem services while providing the necessary gains in food production.

## 5. Reform or Morph: Unlocking value in Asian Irrigation[2]

### 5.1 Asian Irrigation in transition

Gravity-flow irrigation has dominated irrigated agriculture in Asia for millennia. Until European colonial powers began constructing large centrally-managed irrigation systems in the 19th century and later, much irrigation in Asia, barring some exceptions was small-scale and organized around irrigation communities. During the Colonial era, European initiatives in building large irrigation projects under centralized management marked a watershed in Asia's irrigation history; and until the 1940's, much new irrigation development took place under colonial governments which viewed irrigation as a way to blend "interests of charity and the interests of commerce". In India, the British levied enhanced taxes from irrigated land; in Taiwan and China, Japanese sought enhanced rice supplies by investing in irrigation. With the end of Colonialism, the tradition of centralized irrigation-building and management has been continued by national and sub-national governments but for food security and poverty reduction and with significant support from multi-lateral international financial agencies. However, poor management and performance of public irrigation systems was a concern throughout the colonial era; and this concern has multiplied manifold in post-Colonial Asia.

During recent decades, surface irrigation is in decline in many parts of Asia. Public irrigation systems have tended to be underutilized and over-capitalized, and typically serve only a fraction of the designed command. With aging, irrigation commands have been sinking under the weight of their managerial, economic and environmental problems. In the Indian sub-continent, with by far among the largest areas under surface irrigation in Asia, small surface structures, notably tanks in southern India and Rajasthan, *karezes* in Pakistan and Iran, *kuhl's* in the Himalaya's, *ahar-pyne* systems in southern Bihar had been losing irrigated area since the 1950s. But during the 1990s, even large public irrigation systems have begun shrinking. During the 7-year period between 1994 and 2001, India and Pakistan together lost over 5.5 million ha of canal irrigated areas despite massive investments in rehabilitation and new projects (Shah 2008). In Central and South-east Asia, figures are not as dismal; but the present performance and future sustainability of irrigation projects has remained a matter of growing concern.

### 5.1 Institutional Reforms in Surface Irrigation

In recent years, researchers, NGOs, donors and governments have sought to reverse this declining trend through institutional reforms—in the form of Participatory Irrigation Management or Irrigation Management Transfer to farmer associations. This idea itself derives from the variety of farmer-managed irrigation systems (FMIS) that proliferated—and can still be found—in Asia. As with all complex socio-technical systems, to work well, these systems required, generated, and nurtured a "culture of irrigation". So central was this culture to shaping the social lives of irrigators that anthropologist Robert Hunt called such groupings 'irrigation communities'. With large gravity-flow systems constructed by the state, system design and centralized operation acquired greater significance. But despite caution from the

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[2] This section of the paper is largely based on Tushaar Shah's (2008) book *Taming the Anarchy: Groundwater Governance in South Asia*, Washington, D.C.: The Resources for the Future Press

likes of Hunt and sociologist Walter Coward, it has been widely assumed that catalyzing and nurturing vibrant irrigation communities—Water User Associations—in command areas can help large irrigation systems function as well as did traditional FMIS. This assumption is now proving farfetched (see Box 1 for case of Indonesia).

Box 1. Bureaucratic designs: a conceptual fault in IMT policy formulation in Indonesia

> The way irrigation management transfer (IMT) policy has been repeatedly formulated and implemented in Indonesia, without significant change in the farmers-irrigation agency relationship (Bruns, 2003) brings into light the conceptual fault in IMT policy formulation. This conceptual fault is rooted in the way international policy makers perceive the irrigation agency both as a government agency incapable to conduct sectoral development, and as a reform agent responsible for the proposed sectoral reform program. With reference to this dilemmatic presentation of the irrigation agency's roles in IMT (as the defined problem and the proposed solution), the irrigation agency is assumed to lack any identity or interests of their own, and the process of transfer is assumed to be a-political if not neutral (Suhardiman, 2008). Hence, the thinking goes that Water Users Associations (WUAs) or Federation of Water Users Associations (FWUAs) as new farmer organizations can be empowered by the very agency these organizations are formed to replace. In short, with IMT, it is generally believed that high-performance farmer organizations can be formed and developed by an unreformed, inefficient, and corrupt irrigation agency and this has not happened (Suhardiman 2008).

For centuries, the feasibility of catalyzing a viable irrigation community determined the size of irrigation systems. Unsurprising, then, most FMIS were small-scale systems that could be sustained over centuries by local irrigation communities—often with cooperation aided by coercion from local authority structures. These survived and thrived as long as they met three ongoing challenges facing all multi-user irrigation systems:

[a] ***Rule-enforcement:*** to keep in check the *anarchy* endemic to these systems by punishing deviations such as water thefts, vandalism, violation of distribution norms. Anarchy-control ensured efficient and equitable provision of irrigation service and helped maximize 'member-value' but required deft system-management backed by authority.

[b] ***Regular maintenance:*** to counter the *atrophy* endemic to irrigation systems due to gradual disfigurement, arrested only by constant investment in its maintenance and upkeep. Atrophy-control ensured physical sustainability of the systems—which sometimes lasted for centuries--but required ruthless collection of irrigation service fees, often in the form of labor.

[c] ***Upgradation:*** to minimize the *noise* by adapting the system to changing service-expectations of irrigators as changes in farming systems modify irrigation demands. The control of noise—the gap between the service a system is capable of delivering and the service irrigators demand at a point in time--is minimized by constant upgradation to meet changing irrigation demand patterns. Until some decades ago, noise-control was not much of an issue in Asian irrigation. However, during recent decades, with household farming systems in the throes of massive change, noise-control has become a critical driver of irrigation system performance.

Clearly, authority—constituted endogenously within the irrigation community or provided from outside—was always central to sustained control of anarchy and atrophy. Large systems were therefore built and managed effectively only when external authority could enforce rules, and secure resources and labor for maintenance and repair. The Colonial state had the necessary authority as well as incentive to keep anarchy and atrophy in check. In many parts of Asia, the post-Colonial state has neither. Moreover, noise was never as important a performance-depressant in Asian irrigation systems as it is today, what with farmers expecting on-demand irrigation year-round to support intensification and diversification of their subsistence farming. In this sense, decline in community and public irrigation systems is a reflection of larger changes underway in Asian state and society.

## 5.3 Changing Socio-Technical Foundations of Asian Irrigation

Table 9 summarizes a broad-brush selection of socio-technical conditions that prevailed during pre-colonial, colonial and post-colonial eras in many Asian countries. The hypothesis is that particular forms of irrigation organization we find in these eras were in sync with the socio-technical fundamentals of those times. Irrigation communities thrived during pre-colonial times when: [a] there was no alternative to sustained collective action in developing irrigation; [b] strong local authority structures, such as *Zamindars* in Mughal India, promoted—even coerced—collective action to enhance land revenue through irrigation; [c] exit from farming was difficult.

Similarly, large-scale irrigation systems during colonial times kept anarchy, atrophy and noise in check because: [a] land revenue was the chief source of government income, and enhancing it was the chief motive behind irrigation investments; [b] state had a deep agrarian presence and used its authority to extract 'irrigation surplus' and impose discipline in irrigation commands; [c] farmer had practical alternatives neither to subsistence farming livelihoods nor to gravity flow irrigation. These socio-technical conditions created an 'institutional lock-in' that ensured that public irrigation systems performed in terms of criteria relevant to their managers at those times.

Post-colonial Asian societies are confronted with a wholly new array of socio-technical conditions in which neither irrigation communities nor disciplined command areas are able to thrive. The welfare state's revenue interests in agriculture are minimal; the prime motive for irrigation investments is food security and poverty reduction, and not maximizing government income. Governments have neither the presence and authority nor the will to even collect minimal irrigation fees needed to maintain systems. Then, agrarian economies are in the throes of massive change. Farmers can—and do-- exit agriculture with greater ease than ever before. Growing population pressure has made small-holder farming unviable except when they can intensify land use and diversify to high-value crops for a growing urban and export markets. Finally, gravity flow irrigation systems are hit by the mass-availability of small pumps, pipes and boring technologies that have made 'irrigation community' redundant; these have also made the irrigator impervious to the anarchy, atrophy and noise in surface systems, and therefore reduced her stake in their performance.

Table 9. Socio-technical context of surface irrigation in different eras

| | Pre-Colonial (Adaptive Irrigation) | Colonial (Constructive Imperialism) | Post-Colonial (Atomistic Irrigation) |
|---|---|---|---|
| Unit of irrigation organization | Irrigation Community | Centrally managed irrigation system | Individual farmer |
| Nature of the state | Strong local authority; state and people lived off the land; forced labor; maximizing land revenue chief motive for irrigation investments | Strong local authority; land taxes key source of state income; forced labor; maximizing land revenue and export to home-markets chief motive for irrigation investments; state used irrigation for exportable crops | Weak state and weaker local authority; land taxes insignificant; poverty reduction, food security and donor funding key motive for irrigation investments; forced labor impossible; electoral politics interfere with orderly management |
| Nature of Agrarian society | No private property in land. Subsistence farming, high taxes and poor access to capital and market key constraints to growth; escape from farming difficult; most command area farmers grow rice. | No property rights in land. Subsistence farming and high taxes; access to capital and market key constraints to growth; escape from farming difficult; tenurial insecurity; most command area farmers grow uniform crops, majorly rice. | Ownership or secure land use rights for farmers; subsistence plus high value crops for markets; growing opportunities for off-farm livelihoods; intensive diversification of land use; command areas witness a wide variety of crops grown, with different irrigation scheduling requirements |
| Demographics | abundant land going abegging for cultivation; irrigable land used by feudal lords to attract tenants | abundant land going abegging for cultivation; irrigable land used by feudal lords to attract tenants | Population explosion after 1950 and slow pace of industrialization promoted ghettoization of agriculture in South and South-east Asia and China. |
| State of irrigation technology | Lifting of water as well as its transport highly labor intensive and costly; | Lifting of water as well as its transport highly labor intensive and costly; | Small mechanical pumps, cheap boring rigs, and low cost rubber/PVC pipes drastically reduce cost and difficulty of lifting and transporting water from surface and groundwater. |

## 5. 4 Rise of atomistic irrigation

Shrinking of surface irrigation does not mean irrigation areas of Asia are declining overall. In fact, they are not. Old community and government-managed systems are rapidly giving way to a new atomistic mode of irrigation in which millions of small-holders are creating their own mini irrigation systems and scavenge water at will using a mechanical pump, a well and rubber/PVC pipes. The rise of this new water-scavenging irrigation economy is most visible in South Asia and North China plains; here pump irrigation has begun dominating not only dry-land areas but also irrigated areas where public and community irrigation ruled the roost until around 1960's. In India, for example, even as governments keep investing in large, centrally managed surface irrigation projects, over 60% of irrigated areas today are under atomistic pump irrigation. Farmers in India, Pakistan, Bangladesh and Nepal have created more irrigation under this atomistic mode in the past 30 years than governments and colonial powers created in 200 years before. During the 1950's and 60's, Mao's China built massive irrigation systems to water North China plains; but today, the region irrigates mostly with small pumps and boreholes.

The same trend is now also evident in rice economies of South East Asia, for long home to gravity flow irrigation communities. In Sri Lanka, known for its centuries-old tank irrigation of rice paddies, farmers were unfamiliar with irrigation pumps until the 1980s but were using some 106,000 by 2000 to scavenge water from whatever source —wells, tanks, streams—to irrigate dry-season rice and vegetables. By 1999, Vietnamese farmers had pressed in to service more than 800,000 diesel pumps; and in Thailand, farmers increased their pumps from 500,000 in 1985 to more than 3 million in 1999. And the trend was just picking up; Francois Molle found that between 1995 and 1999 alone, Vietnamese farmers purchased 300,000 irrigation pumps, and Thai farmers added a million. Between 1998 and 2002, Indonesian farmers increased their pumps from 1.17 million to 2.17 million. In the Philippines, David Dawe noted that "approximately 23 percent of rice farms now use pumps to access water, either from sub-soil reservoirs, drainage canals, or natural creeks and rivers."

Observers have been struck by the pace of spread of pump irrigation in Southeast Asia. In the Chao Phraya delta of Thailand, 80 percent of farmers were said to have at least one pump, and in Thailand's Mae Klong project, the World Bank estimated that in the early 1990s, a million pumps were drawing water from canals, drains, ditches, and ponds to irrigate dry-season crops. Regarding the Makhamtao-Uthong canal system in Chao Phraya, Facon wrote, "Use of groundwater for irrigation has exploded during the last five years. It is reported that 28,000 tubewells are in use in the region … All the farmers interviewed during the field visit reported having individual pumping equipment used to pump from any possible source of water." The irrigation scene in Asia resembles a palimpsest with layers of old texts that are getting erased to make room for the next one of atomistic, water scavenging irrigation.

The boom in water-scavenging irrigation is supported by the rapid rise of Chinese pump industry, which has pared the cost as well as the weight of their diesel pumps to a fraction of their competitors' products. The Chinese export some 4 million diesel pumps annually; at 1 hectare per pump, these are adding around 4 million ha of atomistic irrigation every year, mostly in South and Southeast Asia. What atomistic irrigation is able to do, that community and public surface irrigation is unable to match, is help farmers control the noise endemic to surface irrigation systems. Hard-pressed by shrinking land holdings and energized by growing markets for high value farm products, Asia's small holders are intensifying as well as diversifying their farming systems; this requires on-demand irrigation year-round. Atomistic irrigation is taking that call. It is making the farmer immune to the anarchy, atrophy and noise in surface systems, and reducing her stake in countering them.

The ascent of atomistic irrigation is at different stages in different parts of Asia as are the socio-technical fundamentals. In South Asia and North China plains, it is peaking, threatening the relevance of irrigation communities and public irrigation itself. In South East Asia, it is at early stages but is already turning the control of anarchy and atrophy in surface irrigation a challenge. In central Asia, the jury is out; well irrigation is rising, especially for backyard garden irrigation, but from a small base.

## 5. 5 Reform or Morph?

In the midst of these changing socio-technical fundamentals, Asia's surface irrigation enterprise is up against some hard questions. Everywhere, PIM/IMT is being tried as the panacea. But can PIM/IMT help restore control of anarchy and atrophy in irrigation systems? Can institutional reforms ensure financial and physical sustainability? Can these help improve rehabilitation of Asia's surface irrigation systems? The evidence from some decades of experiments is far from encouraging; by far the most celebrated experiments—catalyzed, sustained and micro-managed by NGO's with the help of unreplicable quality and scale of resources and donor support--report only modest gains in terms of performance and sustainability, leading researchers to demand 'reform of reforms'.

Low, uncollected irrigation service fees, growing deferred maintenance, rampant anarchy and inequity in water distribution in Asian surface irrigation are symptoms of a larger malaise that PIM/IMT seem unable to address. Unlocking value from Asia's public irrigation capital demands a nuanced exploration of the farmer-system interplay in the context of today's socio-technical fundamentals which differ across Asia. Table 10 presents a first-cut view of socio-technical environment in which irrigation systems function in central Asia, South Asia, South-east Asia and China. Institutional reforms of the PIM/IMT kind appear to have best prospects in central Asia especially if integrated in the estate-mode of irrigated agriculture that European colonial powers popularized in Africa. In China, the model of contracting out distributaries to incentivized contractors seems to have produced better results compared to PIM; and this model needs to be improvised and built upon. The authority and backing of the Village Party Leader seems essential for such privatization to work; and for that reason, this model is unlikely to work in South Asia and South-east Asia. In South East Asia, the key may lie in upgrading and modernizing rice irrigation systems to support dry season rice cultivation as well as diversification of farming systems.

The situation in South Asia suggests that instead of institutional reforms, surface irrigation systems here themselves need to morph to fit in today's socio-technical context. For millennia, irrigation systems were 'supply-driven'. They offered a certain volume of water at certain times with certain dependability; and farmers had no option but to adapt their farming systems to these; they adapted because doing so was better than rainfed farming. Atomistic irrigation—offering water-on-demand year-round--has turned south Asian irrigation increasingly 'demand-driven', giving a whole new meaning to the term 'irrigation management'. With the option of 'exit' available, farmers in command areas are now reluctant to exercise 'voice' through PIM/IMT, refusing to give their loyalty to an irrigation regime that cannot provide them irrigation on-demand year- round.

Table 10. Socio-technical environment of Asia's surface irrigation systems

| | Central Asia | South Asia | South-east Asia | China |
|---|---|---|---|---|
| 1. State's revenue interest in irrigation agriculture | High | Low | Low | Low |
| 2. State's capacity to enforce discipline in irrigation systems | Some to high | Low | Low | High |
| 3. Crops in irrigation commands | Cotton and/or wheat | Monsoon and summer rice, wheat, cotton, sugarcane, fodder, vegetables and fruit | Wet and dry season rice; high value market crops | Rice |
| 4. Government compulsory 'levy' of irrigated crops | yes | No | No | Not any more |
| 5. Spread of pump irrigation within irrigation commands | low | Very high | High | High |
| 6. Population pressure on farm land | low | Very high | High | High |
| 7. Ease of exit from farming | low | Some | High | High |
| 8. Core strategy for unlocking value | Improvise on estate-mode of irrigation farming with PIM or entrepreurial model in distribution | Adapt surface irrigation systems to support and sustain atomistic irrigation; | Modernize irrigation systems to support dry-season rice and diversified farming | Improvise and build upon the incentivized contractor model for distribution and fee collection. |

If we are to unlock the value hidden in South Asia's surface irrigation systems, they must morph in ways they can support and sustain the rising groundswell of atomistic irrigation; and by doing that secure the resources and cooperation they need from farmers to counter anarchy, atrophy and noise. If they themselves cannot become demand-driven, they should try integrating with a demand driven atomistic irrigation economy. This is already happening in many systems but by default; but much hidden value can be unlocked if this happens by deliberate design. This requires a paradigm shift in irrigation thinking and planning.

## 6. New developments, emerging challenges and opportunities for change

Asian irrigation is in a transition and needs to respond to new sets of challenges such as globalization, climate change, changing aspirations and diets and changes in the larger political economy (Shivakoti et al. 2005). Globally there are sufficient land and water resources to produce food for a growing population over the next 50 years and this holds true for Asia as well provided rapid productivity gains can be made in the coming few decades. But it is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world, including Asia. Only if we act to improve water use in agriculture will we meet the acute freshwater challenge facing humankind over the coming 50 years. Challenges facing agricultural water management are different from those 50 years ago. The global population growth rate has slowed down but in absolute terms the global population continues growing before leveling off at around 9 billion by 2050 (50% higher than now). Urbanization and substantially higher incomes will result in a shift in food demand from cereals towards higher value commodities such as meat, milk, oil and sugar. These products typically require more water per calorie consumed. Agricultural markets are changing and new demands such as biofuels are emerging.

A fairly recent development to meet food demands in land scarce countries has been to lease land in other countries, notably that in Africa. Developed and emerging governments and private entities (agribusiness, investment banks and private equity funds) bought rights to large track of arable lands (Redfern November 23, 2008; Branford November 22, 2008)[3]. The purchase of lands was set off by the recent food and financial crisis and represents the governments' long-term strategies to resolve food insecurity that arises from limited land and water supplies. The most important Asian buyers are China, India, Japan, South Korea and Malaysia (Fig. 15). Although China today is self-sufficient in food, its population is growing, its agricultural lands are shrinking as a result of industrialization and urbanization and it is increasingly experiencing water scarcity. The Chinese government has been gradually investing in outsourcing food production (mainly to Africa). Its offshore crops are rice, soybean, maize, cassava and biofuels. India, responding to concerns such as declining soil fertility and long-term water supplies, is buying up lands in Burma, Indonesia and in various countries in South America (Grain 2008).

Food corporations and private investment firms are charged with advancing the strategy of their governments' as well as acting as independent buyers seeking profits. One of the buyers, a South Korean firm called Daewoo Logistics, plans to grow five million tons of corn per year by 2023 on approximately one million ha of agricultural land that it secured for 99 years from Madagascar's government. The land bought by Daewoo represents half of that country's arable land. The company will use an additional 120 000 ha of land to produce palm oil for South Korean markets (Grain 2008).

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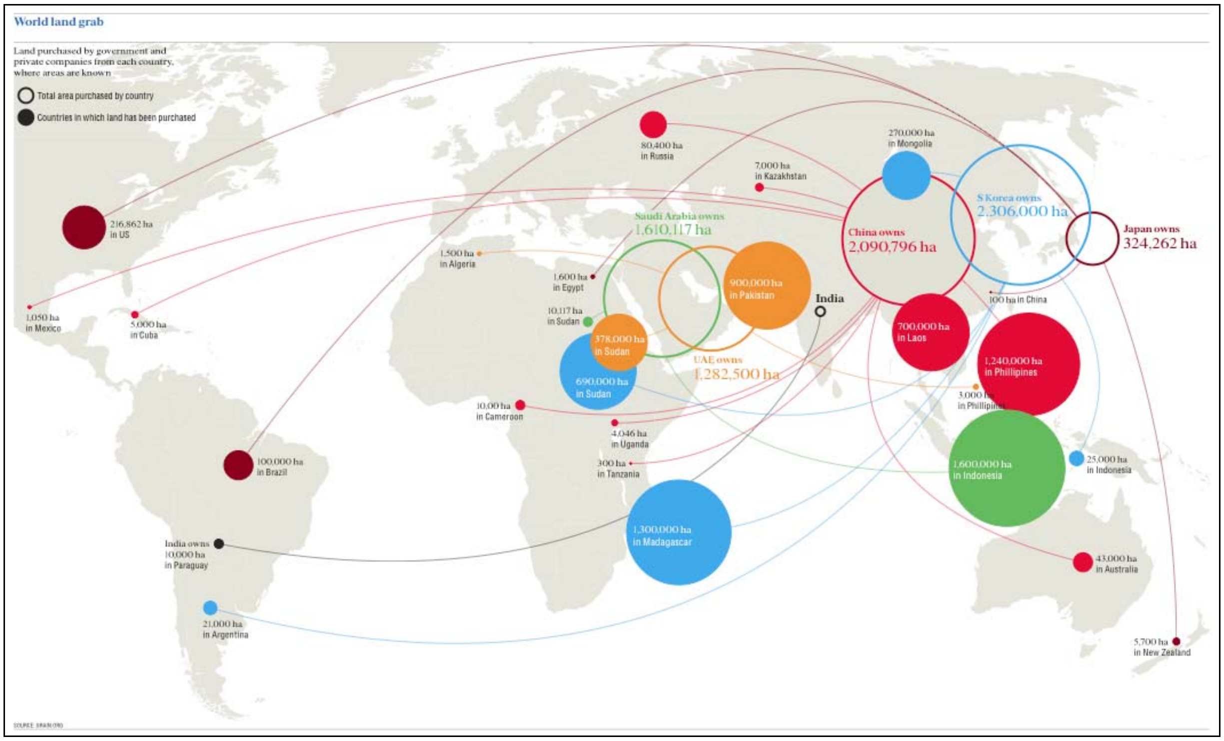
[3] Grain published a document that lists known land transactions. The list contains information about lands that were bought by Asian governments and companies outside Asia and about lands bought by Asian and other governments and companies in Asia. The report may be accessed at http://www.grain.org/briefings_files/landgrab-2008-en-annex.pdf.

Figure 15. Growing food in other continents: Collaboration or colonialism



Source: The Guardian (December 20, 2008)

Lands are being bought up in Central and South East Asia mainly by the Gulf States. The countries that are the most targeted are Burma, Cambodia, Indonesia, Laos, the Philippines, Thailand, Vietnam and Kazakhstan (Grain 2008). The implications and impacts of these developments in terms of modes of farming (whether large farming enterprises will take the place of small landholders), rural development, research and development in agriculture, food security and land and water resources are not well understood.

At the same time water scarcity problems and/or groundwater overdraft are prevalent in an increasing number of river basins in agriculturally important basins in Asia (among others Syr Darya, Nile, Yellow River, and Indus). Maintaining or restoring ecosystem services, contributing to rural development and poverty alleviation and achieving production goals are challenging goals facing agricultural water management. Climate change adds another layer of uncertainty. Water use increases in response to higher food demand. Different strategies to meet this demand have different implications to production goals, environment and poverty alleviation.

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