Water Management for Paddy Rice Production and the Environment

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ABSTRACT

Irrigated agriculture has been and continues to play an essential role in securing the world's food supply. However, it faces severe production limitations. Among others, shrinking of fresh water and cultivable land are the two major constraints. The sustainability of world's food production system is threatened if these constraints are not removed.

Among the three major water-use sectors (agriculture, domestic and industries), irrigated agriculture is by far the biggest user of fresh water. It represents more than two-thirds of world's water withdrawal. It is believed that the capacity to produce more food with less water is possible if irrigation efficiency is significantly improved. As the population increases and economic development intensifies, it is most likely that water from agriculture will be diverted for drinking, sanitation, and industry. Under these conditions, there is no other choice but forces the agricultural production system to be more water-efficient.

Asia, the most populated region in the world, is the world's rice basket. It accounts for 90% of the world's production and consumption of rice. Rice growing, in particular, is a heavy consumer of water. Compared with other crops, rice production is less efficient in the way it uses water. Wheat, for example, consumes 4000 m^3/ha, while rice consumes 7650 m^3/ha.

Paddy agriculture brings about numerous environmental benefits including flood mitigation, groundwater recharge, mitigation of local climate, prevention of landslides and soil erosion and maintaining the bio-diversity. However, increase application of fertilizer to enhance rice yield increases the nitrogen and phosphorus concentration in surface and ground waters that induce eutrophication of water bodies. A proportion of the chemicals applied as pest and weed control pollutes rivers and lakes through runoff, and groundwater through leaching.

While the future trends in water supply for paddy agriculture is of major concern, the outlook in food supply is fairly promising in that most projections show that rice production will keep pace with population growth and the food demand in this region. However, special efforts have to be taken to combat the "water constraint", removing negative while enhancing the positive environmental impacts.

Keywords: Asia, environment, population, paddy field, rice, water.

1. INTRODUCTION

Water is the lifeblood of the planet. It is not equally distributed to all the peoples of this earth. In some regions of the world, water seems to be in abundance. In some parts of this planet, however, there is not enough fresh water to meet the drinking water needs. Unlike oil or energy crisis, fresh water has no viable substitute and it is life-threatening. Its depletion in quantity and quality has profound social, economic and ecological effects. Without water, ecosystems are destroyed. Economic activities halt. People die (UNEP, 2001 & 2002).

In Asia, rice is not only the staple food, but also constitutes the major economic activity and a key source of employment and income for the rural population. Water is the single most important component for sustainable rice production, especially in the traditional rice growing areas of the Region. Reduced investments in irrigation infrastructure, increased competition for water and large water withdrawals from underground water lower the sustainability of rice production. However, despite the constraints of water scarcity, rice production must rise dramatically over the next generation to meet the food needs of Asia's population. Producing more rice with less water is therefore a formidable challenge for the food, economic, social and water security of the Region (Facon, 2003).

1.1 Population Growth and Economic Development in Asia

All rice producing countries in Asia are facing with population pressures. About 3.3 billion people resided here in 2000, make up more than 54% of the world's population (Table 1). The population is increasing at a rate that is very similar to the global population rate of increase. Based on the United Nations estimates, the region's population growth follows a medium to high variance curves (Figure 1). On the average, they are at a rate of increase of approximately 1.4%, annually.

Currently, most countries in this region produce the majority of their own food with 40% of their food produced on the irrigated area. In some countries (i.e. China, Republic of Korea), the amount of irrigated area is either flattening out or is declining. This (flattening out or declining) is not because these countries do not need irrigated land to expand, but rather because they have no cultivable land left and therefore they can no longer expand the amount of land for agriculture. The total area of irrigated lands in most countries in this region has been shrinking over time due to urban development. For example, a modern highway, 10-metre wide and 100 km long, put through prime agricultural land takes away 100 hectares land from prime agricultural production. The numbers of six and eight lane highways that have been constructed over the last two decades in many Asian countries are numerous. Considering the amount of agricultural land has been lost in recent years, new land has to be found to produce more food to feed the growing population. Finding new land for food production is a constraint and a challenge. As good productive land is hard to find, all the newly found lands are marginal (low in fertilities) lands, which generally are more difficult to work and required higher inputs, including energy and water for irrigation. This creates more problems for the rural communities. As mentioned previously, irrigated agriculture produces more food than rainfed agriculture and the preference is still to grow more food by irrigated agriculture. Therefore, in addition to facing the population problem, the region is also facing the problem of finding new land for irrigated agriculture.

Table 1. Asia population (1990 - 2000)

	Population (Million)											Growth Rates (%)	
Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Annual Growth Rate Between	Annual Growth Rate
Afghanistan	16.1	16.4	16.5	17.6	18.7	19.7	20.4	20.9	21.4	21.9	22.7	...	2.9
Azerbaijan	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.7	7.8	8.0	8.0	...	0.9
Bangladesh	108.7	111.0	113.3	115.5	117.7	119.9	122.1	124.3	126.5	128.2	130.2	1.9 (1981-91)	1.7
Bhutan	...	...	...	...	0.6	0.6	0.6	0.6	0.6	0.7	0.7	...	3.0
Cambodia	8.6	8.8	9.0	9.3	9.9	10.2	10.7	10.4	11.4	11.6	12.2	2.0 (1962-98)	3.7
China	1135.2	1150.8	1165.0	1178.4	1191.8	1204.9	1217.6	1230.1	1242.2	1253.6	1262.5	1.5 (1982-90)	0.9
Cook Islands	17.0	18.2	19.0	19.7	19.5	19.4	20.0	18.3	17.4	16.4	17.9	0.4 (1991-96)	-1.6
Fiji Islands	737.0	741.0	745.0	752.0	759.0	768.0	774.0	783.0	793.0	802.0	811.0	0.8 (1986-96)	1.1
Hong Kong, China	5.7	5.8	5.8	5.9	6.0	6.2	6.5	6.6	6.7	6.7	6.8	2.4 (1991-96)	2.0
India	835.1	851.9	868.9	886.3	903.9	922.0	939.5	955.2	975.0	991.0	1002.1	2.1 (1981-91)	1.7
Indonesia	179.4	182.9	186.0	189.1	192.2	194.8	198.3	201.4	204.4	207.4	210.5	2.0 (1980-90)	1.6
Kazakhstan	16.4	16.5	16.5	16.5	16.3	15.8	15.6	15.3	15.1	14.9	14.9	-0.1 (1989-96)	-1.2
Kiribati	71.7	73.3	75.0	76.7	78.4	80.1	82.0	83.9	85.8	87.7	89.6	1.4 (1990-95)	2.3
Korea, Rep. of	42.9	43.3	43.8	44.2	44.6	45.1	45.6	46.0	46.4	46.9	47.3	0.5 (1990-95)	1.0
Kyrgyz Republic	4.3	4.4	4.5	4.5	4.5	4.6	4.7	4.8	4.8	4.9	5.0	1.2 (1989-99)	1.5
Lao PDR	4.1	4.3	4.4	4.5	4.6	4.6	4.7	4.8	5.0	5.1	5.2	2.5 (1985-95)	2.6
Malaysia	17.8	18.6	19.0	19.6	20.1	20.7	21.2	21.7	22.2	22.7	23.3	2.6 (1980-91)	2.4
Maldives	214.0	220.0	226.0	232.0	238.0	245.0	250.0	254.0	259.0	264.0	269.0	2.8 (1990-95)	1.9
Marshall Islands	44.5	45.1	45.8	46.5	47.2	47.9	48.7	49.4	50.1	50.8	51.6	1.5 (1988-99)	1.5
Micronesia Fed.	97.6	99.5	101.5	103.5	105.5	107.6	109.7	111.8	114.0	116.3	118.5	0.2 (1994-00)	1.9
Mongolia	2.1	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.4	2.4	2.5	1.4 (1989-00)	1.4
Myanmar	40.8	41.6	42.3	43.1	43.9	44.7	45.6	46.4	47.3	48.1	...	...	1.8
Nauru	9.4	9.6	9.8	10.0	10.2	10.5	10.8	11.2	11.5	11.6	11.8	2.8 (1983-92)	2.4
Nepal	18.1	18.5	18.9	19.4	19.9	20.3	20.8	21.3	21.8	22.4	22.9	2.1 (1981-91)	2.4
Pakistan	108.0	110.8	113.6	116.5	119.4	122.4	125.4	128.4	131.5	134.5	137.5	2.6 (1981-98)	2.4
Papua New Guinea	3.7	3.8	3.8	3.9	4.0	4.1	4.2	4.2	4.3	4.4	4.4	3.5 (1900-00)	1.5
Philippines	62.0	63.7	65.3	67.0	68.6	70.3	71.9	73.5	75.2	76.8	78.4	2.4 (1995-00)	2.2
Samoa	160.3	161.1	161.9	162.7	163.6	164.4	165.2	166.0	166.9	167.7	170.7	0.3 (1981-91)	0.8
Singapore	3.1	3.1	3.2	3.3	3.4	3.5	3.7	3.8	3.9	4.0	4.0	4.0 (1990-00)	2.6
Solomon Islands	319.0	330.0	342.0	355.0	368.0	382.0	396.0	410.9	426.4	442.4	459.0	3.5 (1976-86)	3.7
Sri Lanka	17.0	17.3	17.4	17.6	17.9	18.1	18.3	18.6	18.8	19.0	19.4	0.1 (1981-94)	1.3
Taipei,China	20.2	20.5	20.7	20.9	21.0	21.2	21.4	21.6	21.8	22.0	22.1	1.2 (1980-90)	0.8
Tajikistan	5.3	5.5	5.6	5.6	5.8	5.8	5.9	6.0	6.1	6.2	6.3	...	1.5
Thailand	55.8	56.6	57.3	58.0	58.7	59.4	60.0	60.6	61.2	61.8	62.4	2.0 (1980-90)	1.0
Tonga	96.4	96.9	97.4	96.8	97.1	97.4	97.8	98.6	99.3	99.8	100.3	0.3 (1986-96)	0.6
Turkmenistan	3.8	3.9	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5.1	5.3		3.1
Tuvalu	9.0	9.0	9.2	9.3	9.4	9.5	9.6	9.8	10.0	10.3	10.5	1.9 (1979-91)	1.9
Uzbekistan	20.5	21.0	21.5	22.0	22.4	22.8	23.2	23.7	24.1	24.4	24.8	...	1.7
Vanuatu	147.3	151.5	155.6	159.8	164.2	168.4	172.9	177.4	182.0	183.7	187.7	2.5 (1979-89)	2.2
Viet Nam	65.8	66.9	68.0	69.2	70.4	71.6	72.8	74.1	75.4	76.6	77.7	1.7 (1989-99)	1.6
TOTAL	2809.6	2858.9	2906.0	2953.8	3002.7	3049.9	3097.5	3141.2	3190.2	3233.5	3270.3		1.4
WORLD	5266.4	5343.3	5421.3	5500.5	5580.8	5662.3	5737.6	5813.9	5891.2	5969.6	6049.0		1.3
Asia/World (%)	53.3	53.5	53.6	53.7	53.8	53.9	54.0	54.0	54.2	54.2	54.1		

Sources: *ADB Statistics and data Systems Division, Sept.13, 2001*
UN, *Demographic Yearkbook 1998.*
UN, *Statistical Yearbook for Asia and the Pacific 2000.*
UN, *World Population Prospects, The 1998 Revision.*

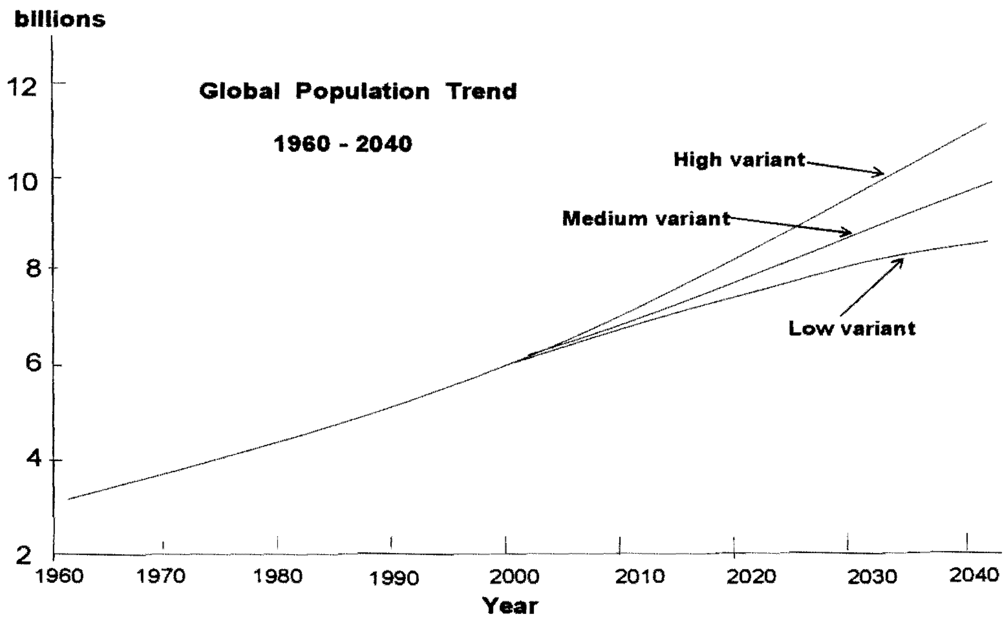

Figure 1. Global population trend

1.2 Climatic Conditions and Water Use in Asia

The paddy rice producing area in Asia is a high rainfall monsoonal zone. This region has characteristic that rainy and dry seasons are distinctly separable under the influence of the monsoon. The precipitation in this area has both seasonal changes and large annual fluctuations. The rice crop in paddy fields supported by the monsoon rainfall is highly developed and the order for water utilization focused on agricultural use is prevailing. In many Asian countries, the demand for water for domestic, municipal, industrial, and environmental purposes has been rising and will continue to rise in the future. As the competition for water from these sectors rises, less water will be available for agriculture. But the potentials for new water resource development projects and expanding irrigated area are limited (Guerra et al. 1998). The natural and social conditions peculiar to the Asian monsoon region must be considered to deal with the water resources development and management (World Water Forum VWF 2003).

Rice is the most widely grown of all crops under irrigation in Asia. There are 120 million hectares of irrigated land in Asia and more than 90% of the world rice is produced in this region. Water use is one of the most urgent issues facing the rice industry today. In Asia, more than 80% of the developed freshwater resource is used for agriculture and irrigation, less than 10% is for domestic and municipal use and about 10% for industry (see Table 2). Population growth and increasing urbanization will increase water demand which, in turn, will lead to irrigation water being reallocated for domestic, municipal and industrial use. This may have serious implications on food production and food security. As paddy agriculture is a heavy consumer of water, it needs innovative technologies and practices in order to achieve sustainable development and to meet the food demand (ICID Workshop, 2000). Several countries in Southeast Asia are considering introducing water rights to improve the allocation of water among different uses (ADB, 2000).

Table 2. Water Withdrawal in Asia

Country	**Year**	**Agricultural**		**Domestic**		**Industrial**		**Total**
		million m^3	**% of total**	**million m^3**	**% of total**	**Million m^3**	**% of total**	**million m^3**
Bangladesh	1990	12,600.00	86	1,704.32	12	332.16	2	14,636.48
Bhutan	1987	10.80	54	7.20	36	2.00	10	20.00
Cambodia	1987	489.00	94	26.00	5	5.00	1	520.00
China	1993	407,774.00	77	25,165.00	5	92,550.00	18	525,459.00
India	1990	460,000.00	82	25,000.00	5	15,000.00	3	500,000.00
Indonesia	1990	69,241.00	93	4,729.00	6	376.00	1	74,346.00
Japan	1992	58,600.00	64	17,000.00	19	15,800.00	17	91,400.00
Korea, DPR	1987	10,336.00	73	1,557.60	11	2,265.60	16	14,160.00
Korea, Rep.	1994	14,877.00	63	6,209.00	26	2,582.00	11	23,668.00
Lao PDR	1987	812.00	82	79.00	8	99.00	10	990.00
Malaysia	1995	9,750.00	77	1,342.00	10	1,641.00	13	12,733.00
Maldives	1987	0.00	0	3.32	98	0.05	2	3.37
Mongolia	1993	227.04	53	85.36	20	115.72	27	428.12
Myanmar	1987	3,564.00	90	277.20	7	118.80	3	3,960.00
Nepal	1994	28,702.00	99	246.00	1	5.00	0	28,953.00
Papua New Guinea	1987	49.00	49	29.00	29	22.00	22	100.00
Philippines	1995	48,857.00	88	4,269.00	8	2,296.00	4	55,422.00
Sri Lanka	1990	9,380.00	96	195.00	2	195.00	2	9,770.00
Thailand	1990	30,200.00	91	1,496.00	5	1,436.00	4	33,132.00
Vietnam	1990	47,000.00	86	2,000.00	4	5,330.00	10	54,330.00
Total		**1,212,468.84**	**84**	**91,420.00**	**6**	**140,171.33**	**10**	**1,444,030.97**

1.3 Paddy Agriculture and the Environment

Paddy agriculture in the monsoon region of Asia has multi-functions including food supply to meet the need of ever-increasing population, economic development and the vitalization of rural community. These multi-functions of paddy agriculture will continue to be effective for the sustainable development of agriculture and rural areas (ICID Workshop, 2000). The following are some salient environmental functions of paddy agriculture.

- **Flood mitigation by paddy fields**: the levees of paddy fields function like the dikes of dams. Levees surrounded paddy fields (about 15 to 30 cm high) can store and regulate the discharge of heavy rainfall. Abdullah (2002) reported that, in Malaysia, one hectare of paddy field has a reservoir capacity of 3000 cubic meters. In Korea, paddy fields stored a total of 2,733 million metric tons of water (Suh, 2001). When this flood mitigation function is translated into equivalent economic values, an amount of US$1090 million in Korea and US$239910 million in Japan was reported by Kwun (2002).

- **Groundwater recharge from paddy fields**: flood irrigation is normally practised for paddy fields. A depth of 10 to 15cm standing water is generally maintained prior to harvesting. A significant amount of water percolates through the soil and recharges to the groundwater. Though much of the percolated water flows back into the rivers or drainage channels, about 7% goes towards recharging the underground aquifers (Abdullah, 2002). Removal of groundwater is expected to increase due to increasing demand of freshwater. Excessive removal of groundwater without adequate recharge will cause the ground to consolidate resulting in land subsidence. Paddy fields provide a very important source of groundwater replenishment (Mizutani, 2002)

- **Mitigation of local climate** : the paddy fields have been found to have the air-cooling effect. The standing water in paddy fields plays an important role not only the production of rice and recharging groundwater but also on the redistribution of solar energy at the surface of the earth through evapotranspiration. When water evaporated from surfaces of rice fields and plants into the atmosphere, it takes up heat from the air, lowering the atmospheric temperature. The differences in energy balance and surface temperature among various types of land use influences the air temperature environment. Study has shown that air temperature above the paddy fields is lower (up to 2°C) than that of the surrounding area (Abdullah, 2002)

- **Prevention of landslides and soil erosion**: soil erosion caused by heavy monsoon rainfall event is common in monsoonal Asia region. Soil erosion leads to loss of soil fertility and agricultural productivity. It also induces sedimentation and flooding downstream. Paddy fields with its level surface and constructed levees can reduce the impact of rainfall on soil surface and retain soil eroded from the upland area. Terraced paddy fields in hilly lands have the most ideal configuration in preventing soil erosion and landslide. While paddy fields can not eliminate the soil erosion completely, it helps to reduce the amount of soil loss from upland.

- **Maintaining bio-diversity** : paddy fields offer homes to some hundreds species of terrestrial and aquatic insects, both resident and migratory. The fields serve as both feeding and dwelling places for water birds including migratory birds. Many types of fish and amphibians also live in paddy fields. This bio-diversity is possible because the paddy fields are linked to canals and rivers. If the paddy fields disappear, the waterways linking to rivers and paddy fields which fish can come and go will be lost.

While the paddy cultivation provides numerous positive effects on the environment as mentioned above, it has caused various negative impacts on the environment. Emission of methane, one of the greenhouse gases, is one of the concerns. Increase application of fertilizer to enhance rice yield increases the nitrogen and phosphorus concentration in surface and ground waters. These nutrients induce eutrophication of water bodies. A proportion of the chemicals applied as pest and weed control pollutes rivers and lakes through runoff, or groundwater through leaching. In some upland areas, intensive agricultural practices, coupled with deforestation, have resulted in high rates of soil erosion and degradation of both land and water resources in lowland below. The effects can reach as far as coastal waters, with consequent impact on marine life (Spurgeon, 1995).

2.OUTLOOKS

Since 1970, the population of Asia has increased by one-third, while the area of arable land per head of population has fallen by half and the availability of water resources per capita declined by 40–60% in many countries in this region. More food has to be produced from less land and water than ever before. At the same time, agricultural production faces long-term threats to productivity with the climatic changes of global warming, as well as the environmental changes which decades of intensive farming have brought to both lowland and upland fields.

The potential for expanding the area planted in rice appears to have become very restricted in Asia. Most land resources have already been exploited to their fullest extent, and most of the readily manageable water resources also have been developed to irrigate paddy fields. Therefore, any further increase in the production of rice depends heavily on intensification in existing rice lands (Kyuma, 1995).

The likely outcome of the unprecedented industrial and urban growth in the past decade experienced by many Asian countries is increased diversion of water from agricultural sector, especially those that are near growth centers, for nonagricultural purposes. Increased competition for water between sectors already affects agriculture in China, India, Malaysia, Thailand and the Republic of Korea and the trend is towards an intensification of the problem due mainly to the rapid growth of the domestic and industrial sectors in these countries (Facon, 2003). Major inter-basin water transfer programmes are reported in China, Thailand and India.

Overexploitation of groundwater and disposal of untreated or under-treated industrial and domestic wastes into freshwater bodies will further diminish agriculture's share of water in both quantity and quality. Because urban and industrial demands are likely to receive priority over irrigation, water supply for agricultural use is expected to decrease, especially in years with a low water supply at the source. The future of rice production will therefore depend heavily on developing and adopting strategies and practices that will use water more efficiently in irrigation schemes (Guerra et al., 1998).

While the future trends in irrigation water supply for paddy agriculture is of major concern, the outlook in food supply and demand is fairly promising in that most projections show that agricultural production will keep pace with population growth and the increases in demand generated by rising incomes. Asian economies are expected to grow at faster than global rates, while trade liberalization should lower food prices in Asia and free funds that currently used to subsidize domestic production.

3. CONCLUSION

Rice is the most widely grown of all crops under irrigation in Asia. It is not only the staple food, but also constitutes the major economic activity and a key source of employment and income for the rural population in this region. Water use is one of the most urgent issues facing the rice industry today. In Asia, about 80% of the developed freshwater resource is used for agriculture and irrigation. Population growth and increasing urbanization will increase water demand which, in turn, will lead to irrigation water being reallocated for domestic, municipal and industrial use. This may have serious implications on food production and food security. As paddy agriculture is a heavy consumer of water, it needs innovative technologies and practices in order to achieve sustainable development and to meet the food demand. Producing more rice with less water is therefore a formidable challenge for the food, economic, social security of the Region

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Paddy agriculture in the monsoon region of Asia has multi-functions including food supply to meet the need of ever-increasing population, economic development and the vitalization of rural community. It brings about numerous positive effects on the environment including flood mitigation, groundwater recharge, mitigation of local climate, prevention of landslides and soil erosion and maintaining the bio-diversity. However, increase application of fertilizer to enhance rice yield increases the nitrogen and phosphorus concentration in surface and ground waters that induce eutrophication of water bodies. A proportion of the chemicals applied as pest and weed control pollutes rivers and lakes through runoff, and groundwater through leaching.

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