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SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES IN ASIA : A COMPARATIVE STUDY

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SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES IN ASIA: A COMPARATIVE STUDY

Introduction

It is paradoxical that although water seems to be the most abundant resource available on the earth, governments, international organizations and policy makers are talking of an emerging water crisis. This paradox can partly be explained by the fact that although water is seemingly so plentiful, of the world's water resources about 97.5 percent is too salty and hence unfit for human consumption and crop production (Saleth and Dinar, 2004). Of the remaining water resources which constitutes fresh water resources most of it i.e. an estimated 35 mil cubic kilometers per year cannot be fully accessed since most of it is locked either in the ice cover of the Artic or Antarctic regions, or in deep underground aquifers (Saleth and Dinar, 2004). The physically accessible freshwater potential of the world is estimated at only 90,000 cu.km per year or just 0.26 percent of global freshwater resources (Saleth and Dinar, 2004). However, even of the physically accessible freshwater resources only about 12,500 cubic meters can be accessed under present economic and technical conditions (FAO, 1996, vide Saleth and Dinar, 2004). Owing to increasing population, incomes, and economic growth, extension and intensification of agriculture, rapid urbanization and industrialization demand for water is expanding fast putting great strain on the available water resources and on global, regional, national and local economies. Added to that climatic-induced variations in the level and spatial pattern of global temperature and precipitation are going to further affect utilization of the accessible freshwater resources (Saleth and Dinar, 2004). In fact water is turning out to be the most important constraint for sustaining human life and economic activity and in the days to come the water crisis as it is popularly referred to is going to be the most important factor impeding and sustaining economic growth. What is more disturbing is that it is the developing countries especially in Africa and Asia struggling to increase their living standards that are going to be hit the hardest by the emerging water crisis. By the year 2025 it is estimated that about 2 billion people will live in countries or regions with absolute water scarcity. Most countries in the Middle East and North Africa are presently classified as having absolute water scarcity (www.iwmi.org 2005). By 2025 these countries will be joined by Pakistan, South Africa and large parts of India and China (www.iwmi.org 2005). It is reported that many countries especially in the Middle East are nearing or exceeding their renewable water supply limit (Gleick, 1993, vide Saleth and Dinar, 2004). Fifty-five countries in Africa and Asia are unable to meet the basic water needs of their growing population. It is noted that about 2.2 billion people in the world especially in developing countries do not have access to clean water and about 2.7 billion people do not have access to sanitation services (Gleick, 1998, vide Saleth and Dinar, 2004). Poor access to safe water and sanitation also leads to high health and economic costs due to water borne diseases such as diarrhea, typhoid, gastro-enteritis, malaria, and water pollution. Water is also being increasingly regarded as a basic human right. Water-related conflicts between households, regions and even countries over accessing and sharing of water resources is also giving rise to social and political tensions. Hence, fulfilling the basic human needs for water and also meeting the expanding water needs of an expanding population and economies is proving to be a great challenge. Against the background of the global water scenario, this study seeks to assess the prospects and constraints for sustainable use and management of water resources in Asia. Apart from reviewing the global water resources situation from the global and Asian perspectives, the study also analyses the trends and projections of water consumption up to the year 2025, water pricing, water productivity, water quality, health and sanitation, as well as water institutions and markets.

Water Resources: Global and Asian Perspective

A review of the global water resources and in selected Asian countries in particular is presented here. Information on the region wise and country wise distribution of freshwater resources are furnished in Table 1. The annual renewable water resources in the world are estimated at around 43,219 km^3 during 2003. Bulk of this is accounted by surface water, followed by groundwater recharge and overlap. While developed countries accounted for 13,016 km^3 of internal renewable water resources, the developing countries accounted for 29,289 km^3. A look at the region wise situation shows that South America, followed by Asia, Europe and North America claim the highest share in the annual renewable water resources. If we look at the water resources situation among Asian countries, it is seen that Indonesia, followed by China, India, Bangladesh and Myanmar and among non-Asian countries Brazil, followed by Canada, USA, and Colombia report the highest quantum of renewable water resources. However, on per capita basis Cambodia, followed by Malaysia, Myanmar and Mongolia rank the highest among Asian countries in terms of annual renewable water resources whereas among non-Asian countries Congo, Canada, Venezuela, Colombia, Brazil rank the highest. Among the Asian countries per capita availability of annual renewable water resources is relatively the lowest for Korea Republic (1471 m^3 per capita), India (1822 m^3 per capita), China (2186 m^3 per capita) and Pakistan (2812 m^3 per capita). On per capita basis the availability of annual renewable water resources is very high in a number of South American and African countries as compared to among most Asian countries.

Table 1: Region and countrywise Distribution of Freshwater Resources - 2003

Region/Country	**Annual Renewable Water Resources**					
	Internal Renewable Water Resources				**Natural Renewable Water Resources**	
	Ground-water Recharge	**Surface water**	**Overlap**	**Total**	**Total (km^3)**	**Per Capita (m^3 per person)**
		(in km^3)				
World	11358	40594	10067	43219	-	-
Asia (excluding Middle East)	2472	10985	2136	11321	-	-
Europe	1318	6223	986	6590	-	-
Middle East/N. Africa	149	374	60	518	-	-
Sub-Saharan Africa	1549	3812	1468	3901	-	-
North America	1670	4702	1522	4850	-	-
C. America & Caribbean	359	1050	231	1186	-	-
South America	3693	12198	3645	12246	-	-
Oceana	-	1241	20	1693	-	-
Developed	3153	12084	2584	13016	-	-
Developing	8128	28500	7483	29289		
<u>Countries</u>						
<u>Asia</u>						
Bangladesh	21	84	0	105	1211	8444
Cambodia	18	116	13	121	476	34561
China	829	2712	728	2812	2830	2186
India	419	1222	380	1261	1897	1822
Indonesia	455	2793	410	2838	2838	13046
Japan	27	420	17	430	430	3372
Korea DPR	13	66	12	67	77	3415
Korea Rep.	13	62	11	65	70	1471
Malaysia	64	566	50	580	580	25178
Mongolia	6.1	33	4	35	35	13451
Myanmar	156	875	150	881	1046	21358
Nepal	20	198	20	198	210	8703
Pakistan	55	47	50	52	223	2812
Philippines	180	444	145	479	479	6093
Sri Lanka	7.8	49	7	50	50	2592
Thailand	42	199	31	210	410	6371
Vietnam	48	354	35	367	891	11109

Other Countries						
France	100	177	98	179	204	3414
Germany	46	106	45	107	154	1878
U.K.	9.8	144	9	145	147	2464
Iran	49	97	18	129	138	1900
Turkey	69	186	28	227	229	3344
Cameroon	100	268	95	273	286	18378
Congo	198	222	198	222	832	259547
Congo D.R.	421	899	420	900	1283	23639
Canada	370	2840	360	2850	2902	92810
U.S.A.	1300	1862	1162	2800	3051	10574
Brazil	1874	5418	1874	5418	8233	47125
Colombia	510	2112	510	2112	2132	49017
Venezuela	227	700	205	722	1233	49144
Australia	72	440	20	492	492	25185

Notes:

Internal Renewable Water Resources (IRWR) includes the average annual flow of rivers and the recharge of groundwater (aquifers) generated from endogenous precipitation occurring within a country's border. IRWR are measured in cubic kilometers per year (km^3/year).

Groundwater Recharge the total volume of water entering aquifers within a country's border from endogenous precipitation and surface water flow. Groundwater resources are estimated by measuring rainfall in arid areas where rainfall is assumed to infiltrate into aquifers. Where data are available, groundwater resources in humid areas have been considered as equivalent to the base flow of rivers.

Surface Water produced internally includes the average annual flow of rivers generated from endogenous precipitation and base flow generated by aquifers. Surface water resources are usually computed by measuring or assessing total river flow occurring in a country on a yearly basis.

Overlap is the volume of water resources common to both surface and groundwater. It is subtracted when calculating IRWR to avoid double counting. Two types of exchanges create overlap: contribution of aquifers to surface flow, and recharge of aquifers by surface run-off. In humid temperate or tropical regions, the entire volume of groundwater recharge typically contributes to surface water flow. In karstic domains (regions with porous limestone rock formations), a portion of groundwater resources are assumed to contribute to surface water flow. In arid and semi-arid countries, surface water flows recharge groundwater by infiltrating through the soil during floods. This recharge is either directly measured or inferred by characteristics of the aquifers and piezometric levels.

Total Internal Renewable Water Resources is the sum of surface and groundwater resources minus overlap; in other words, IRWR = Surface Water Resources + Groundwater Recharge – Overlap.

Natural Renewable Water Resources, measured in cubic kilometers per yea (km^3/year), is the sum of internal renewable water resources and natural flow originating outside of the country. Natural Renewable Water Resources are computed by adding together both internal renewable water resources (IRWR – see above) and natural flows (flow to and from other countries). Natural incoming flow is the average amount of water that would flow into the country without human influence. In some arid and semi-arid countries, actual water resources are presented instead of natural renewable water resources. These actual totals, labeled with a footnote in the freshwater data table, include the quantity of flows reserved to upstream and downstream countries through formal and informal agreements or treaties. The actual flows are often much lower than natural flow due to water scarcity in arid and semi-arid regions.

Per Capita Natural Renewable Water Resources are measured in cubic meters per person per year (m^3/person/year). Per capita values were calculated by using national population data for 2002. For more information about the collection methodology and reliability of the UN data, please refer to the technical notes in the population data table.

Source: www.wri.org downloaded on 18.01.2005

Table 2 furnishes the country wise distribution of annual freshwater withdrawals and sectoral share for selected Asian and other countries during 2003. Per capita annual water withdrawals among the selected Asian countries range from 60 m^3 per capita in Cambodia to between 1382 to 1451 m^3 per capita in Pakistan and Nepal. For most of the Asian countries under review the per capita annual water withdrawals exceed 400 m^3 per capita. For non-Asian countries the per capita annual water withdrawals range between 10 m^3 per capita in the Congo to between 1600 to 1834 m^3 per capita in Canada and the USA. If one looks at the annual water withdrawals as a proportion of renewable water resource for the Asian countries under review, it is seen that this proportion varies from 1 to 3 percent or less in Mongolia, Bangladesh, Indonesia, Cambodia and Myanmar to 100 percent in Pakistan. For most of the other Asian countries the annual water withdrawals as a proportion of renewable water resources ranges between 20 to 36 percent. The agricultural sector accounts for bulk of annual water withdrawals exceeding or around 90 percent for many Asian countries. The rest is accounted by the domestic and industrial sectors. For the world as a whole agriculture's share in annual water withdrawals was over 70 percent, followed by 20 percent by the industrial sector and the rest by the domestic sector. The non-Asian countries under review show diverse trends. While developed countries like France, Germany, the U.K. and Canada indicate the industrial sector's share in annual water withdrawals to be dominant ranging around or exceeding 70 percent, some of the African countries and Latin American countries report the domestic sector as the main consumer of annual water withdrawals. While among African countries the low level of agricultural development, especially irrigated agriculture may explain this trend, among Latin American countries the high ratio of urbanization explains the reason as to why the domestic sector claims the highest share.

Table 2: Countrywise Distribution of Annual Freshwater Withdrawals and Sectoral Share of Water Withdrawals - 2003

Country	**Annual Water Withdrawals**			**Sectoral Share**		
	Total (Mil m^3)	**Per Capita (m^3 per person)**	**As % of Renewable Water Resources**	**Agriculture**	**Domestic**	**Industry**
World	3,414,000	650	-	71	9	20
<u>Asia</u>						
Bangladesh	14,636	133	2	86	15	2
Cambodia	520	60	0	94	5	1
China	525,489	439	20	78	5	17
India	500,000	592	32	92	5	3
Indonesia	74,346	407	3	93	6	1
Japan	91,400	735	22	64	19	17
Korea DPR	14,160	742	22	73	11	16
Korea Rep.	23,668	531	36	63	26	11
Malaysia	12,733	636	3	77	11	13
Mongolia	428	182	1	53	20	27
Myanmar	3,960	103	0	90	7	3
Nepal	28,953	1451	17	99	1	0
Pakistan	155,600	1382	100	97	2	2
Philippines	55,422	811	13	88	8	4
Sri Lanka	9,770	574	22	96	2	2
Thailand	33,132	605	10	91	5	4
Vietnam	54,330	822	7	87	4	10
<u>Other Countries</u>						
France	32,300	547	16	10	18	72
Germany	46,270	579	31	20	11	69
U.K.	11,790	204	8	3	20	77
Iran	70,034	1122	59	92	6	2
Turkey	35,500	558	17	73	16	12
Cameroon	400	38	0	35	46	19
Congo	40	20	0	11	62	27
Congo D.R.	357	10	0	23	61	16
Canada	45,100	1607	2	12	18	70
U.S.A.	467,340	1834	26	42	13	45
Brazil	54,870	359	1	61	21	18
Colombia	8,938	228	0	37	59	4
Venezuela	4,100	382	1	46	44	10
Australia	14,600	933	4	33	65	2

Notes:

Water Withdrawals (annual), measured in million cubic meters, refers to total water removed for human uses in a single year, not counting evaporative losses from storage basins. Water withdrawals also include water from nonrenewable groundwater sources, river flows from other countries, and desalination plants.

Per Capita Annual Withdrawals were calculated using national population data for the year the withdrawal data were collected.

Water Withdrawals as a Percent of Renewable Water Resources is the proportion of renewable water resources withdrawn on a per capita basis, expressed in cubic meters per person per year (m^3/person/year). The value is calculated by dividing water withdrawals per capita by actual renewable water resources per capita.

Sectoral Share of water withdrawals, expressed as a percentage, refers to the proportion of water used for one of three purposes: agriculture, industry, and domestic uses. All water withdrawals are allocated to one of these three categories.

Agricultural uses of water primarily include irrigation and, to a lesser extent, livestock maintenance.

Domestic uses include drinking water plus water withdrawn for homes, municipalities, commercial establishments, and public services (e.g. hospitals).

Industrial uses include cooling machinery and equipment, producing energy, cleaning and washing goods produced as ingredients in manufactured items, and as a solvent.

Source: www.wri.org downloaded on 18.01.2005

Information on the country wise distribution of groundwater recharge and withdrawals for selected countries in Asia and other region is presented in Table. 3. The per capita average annual groundwater recharge for the Asian countries under review varies from 163 cu.m in Bangladesh to between 2300 to 3420 cu.m in Philippines, Malaysia and Myanmar. For non-Asian countries this figure ranges from 167 cu.m in the U.K. to over 67,000 in the Congo. If one looks at the annual groundwater withdrawals as a proportion of the annual groundwater recharge it is seen that the Asian countries under review show wide variations in this regard. It ranges from less than 2 percent in Malaysia, Thailand and Vietnam to 100 percent or more in Pakistan. In countries like Bangladesh, India, Japan this proportion ranges between 45 to over 50 percent. The per capita annual groundwater withdrawals show wide variations across Asian countries ranging from less than 20 cu.m. in Vietnam, Thailand and Malaysia to over 489 cu.m. in Pakistan. For non-Asian countries under review per capita annual groundwater withdrawals are relatively the highest for Iran (around 738 cu.m) and the USA (around 432 cu.m.); for the other non-Asian countries under review its ranges between 37 to over 143 cu.m.

Table 3: Countrywise Distribution of Groundwater Recharge and Withdrawals (2000)

Country	Average Annual Groundwater Recharge		Annual Groundwater Withdrawals		
	Total (cubic km)	Per Capita (cu.m) 2000	Total (cubic km)	% of Annual Recharge	Per Capita (cu.m)
Asia					
Bangladesh	21	163	10.7	50.9	97.6
Cambodia	17.6	1576	-	-	-
China	828.8	649	52.9	6.4	47.1
India	418.5	413	190	45.4	223.3
Indonesia	455	2145	-	-	-
Japan	27	213	13.6	50.3	108.2
Korea DPR	21	874	-	-	-
Korea Rep.	13.3	284	2.5	18.6	55.1
Malaysia	64	2877	0.4	0.6	19
Mongolia	6.1	2291	0.4	5.8	149.1
Myanmar	156	3420	-	-	-
Nepal	-	-	-	-	-
Pakistan	55	351	60	109.1	489.5
Philippines	180	2369	4	2.2	82.8
Sri Lanka	7.8	414	-	-	-
Thailand	41.9	682	0.7	1.7	15.0
Vietnam	48.0	601	0.8	1.7	11.9
Other Countries					
France	100	1693	6	6	103.8
Germany	45.7	556	7.1	15.5	89.4
U.K.	9.8	167	2.5	25.2	42.4
Iran	42	620	29	69	738.8
Turkey	20	300	7.6	38	124
Cameroon	100	6629	-	-	-
Congo	198	67,268	-	-	-
Congo D.R.	421	8150	-	-	-
Canada	370	11,879	1	0.3	37.3
U.S.A.	1514	5439	109.8	7.3	432.3
Brazil	1874	11,016	8	0.4	57
Colombia	510	12051	-	-	-
Venezuela	227	9392	-	-	-
Australia	72	3812	2.2	3.1	143.2

Notes:

Average Annual Groundwater Recharge is the amount of water that is estimated to annually infiltrate soils, including water from rivers and streams that lose it to underlying strata. In general, this figure would represent the maximum amount of water that could be withdrawn annually without ultimately depleting the groundwater resource. These data are estimated in a variety of ways and caution should be used in comparing values for different countries.

Per Capita Groundwater Recharge is the amount of water that annually infiltrates soils on a per person basis, using 2000 population estimates from the U.N. Population Division.

Annual Total Groundwater Withdrawals refers to abstractions from all groundwater sources – even nonrenewable sources. The percentage of annual recharge refers to total groundwater withdrawals. Per capita annual withdrawals were calculated using national population data for the year of data shown.

Source: www.wri.org downloaded on 18.01.2005

Table 4 presents data on the extent, population density and per capita availability of water across major watersheds in Asia. As evident the largest of these watersheds include ob, Indus, Yenisey, Yangtze, and Tarim. The population density in the major watersheds in Asia range between less than one person per km^2 in Indigirka and Kolyma to between 260 to 400 persons per km^2 in the Ganges and Krishna. Comparatively the population density is the highest for the major watersheds in the Indian subcontinent. The per capita annual availability of water across the major Asian watersheds shows wide variations ranging from around 361 m^3 in Huang He to over 973,000 m^3 in Indigirka. Thus from the above discussion we note that Asian countries and countries in other regions show wide variation in terms of their water endowment, quantum and pattern of water consumption, etc. While some countries are blessed with abundant water resources others are not that fortunate. Further while per capita availability and consumption of water resources is quite high in some countries, in others they are quite low. Across regions one finds wide variations in the sectoral shares of water consumption. While in most Asian countries the agricultural sector is the major consumer of water resources, in some developed countries the industrial sector is the major consumer of water; whereas in some South American and African countries the domestic sector is the major consumer.

Table 4: Information on Major Watersheds in Asia - 2000

Major Watersheds	Modelled Watershed Area (km^2)	No. of Countries	Average Population Density (persons per km^2)	Water Available Per Person (m^3/person/year)
Amu Darya	534,739	5	39	3211
Amur	1,929,955	3	34	4917
Brahmaputra	651,335	4	178	-
Chao Phrya	178,785	1	122	1237
Ganges	1,016,124	4	398	-
Godavari	319,810	1	203	1602
Hong	170,888	2	191	3083
Huang He	944,970	1	157	361
Indigirka	277,818	1	<1	973,515
Indus	1,081,718	4	163	830
Irrawady	413,710	3	78	18,614
Kizil	122,277	1	55	1171
Kolyma	679,934	1	<1	722,456
Krishna	226,037	1	263	786
Kura Araks	205,037	5	75	1121
Lake Balkhash	512,015	2	11	439
Lena	2,306,743	1	1	161,359
Mahanadi	145,816	1	198	2171
Mekong	805,604	6	71	8934
Narmada	96,271	1	177	2159
Ob	2,972,493	4	10	14,937
Salween	271,914	3	22	23,796
Syr Darya	782,617	4	28	1171
Tapti	74,627	1	239	1107
Tarim	1,152,448	2	7	754
Tigris & Euphrates	765,742	4	57	2189
Xun Jiang	409,480	2	194	3169
Yalu Jiang	48,331	2	102	3628
Yangtze	1,722,193	1	212	2265
Yenisey	2,554,388	2	3	79,083

Notes: 1. Major watersheds listed here include major and smaller river systems in Asia. Modelled watershed area was estimated to a resolution of 1 sq.km. These values only reflect horizontal extent and may underestimate total land surface in the drainage area.

2. Average population density was extracted from a 2.5 minute resolution population map. Basins were overlaid on population data, and the population density was calculated for each basin.

3. Water available per person indicates the amount of total runoff available per person in each river basin. Water availability per person was estimated by dividing the total runoff available in a basin by the total number of people in that basin.

Source: www.wri.org downloaded on 18.01.2005

Water Consumption- Trends and Projections

With water becoming a scarce commodity and a limiting factor for economic growth and livelihoods, finding ways for sustainable use and management of available water resources is proving to be a major challenge. What are the likely scenarios in the near future? In this context Rosegrant et al (2002) have made detailed projections of the likely scenarios up to 2025 under alternate assumptions. They tried to assess water consumption and use under three alternate scenarios i.e. Business As Usual (BAU) scenario, Water Crisis Scenario (CRI) and Sustainable Water Use Scenario (SUS). While under BAU water use is expected to continue as per trends in the recent past whereby current trends for water investment, water prices and management are broadly maintained, under CRI the water situation is projected to deteriorate for water and food policy, whereas SUS envisages a more positive future with greater environmental water conservation, greater domestic consumption from full water connection of urban and rural households, and maintenance of BAU levels of food production (Rosegrant et al, 2002). Table 5 that presents the water consumptions projections under these three alternate scenarios shows that CRI and SUS scenarios influence the use of water differently. While under CRI consumptive water use increases significantly, under SUS substantial water savings occur. By 2025 total worldwide water consumption under CRI is expected to be 13 percent or 261 cubic km higher than that under BAU, whereas under SUS it is expected to be 20 percent or 408 cubic km lower as compared to the BAU situation. The difference in the water consumption between CRI and SUS is largely accounted by the irrigation sector i.e. 253 cubic km difference mainly due to declining water use efficiency, higher losses through non beneficial water consumption and greater water withdrawals to compensate for these losses. Under SUS irrigation water consumption declines by 296 cubic km compared with BAU levels mainly through reduction in non-beneficial consumption due to higher water prices and higher water use efficiency. Interestingly developing countries and Asian countries are more negatively affected under CRI and more positively under SUS. While total water consumption in developing countries would increase by 8 percent or 225 cubic km compared to BAU levels, for developed countries it would increase by 8 percent or 36 cubic km. However, under SUS total water consumption in developing countries will decrease by 2 percent or 357 cubic km as against 11 percent or 52 cubic km for developed countries. For Asia as a whole and China, India, south and south east Asia, total water consumption and total irrigation water consumption are projected to substantially increase under CRI as compared with BAU levels, whereas under SUS they are expected to decline substantially. For instance total water consumption in Asia is projected to increase to 1371 cubic km under CRI as compared to 1206 cubic km under BAU, whereas under SUS it is expected to fall to 949 cubic km. Under SUS all the regions in the world show lower water consumption as compared with BAU levels. Overall for the world total water consumption under CRI is projected to increase to 2342 cubic km compared to 2081 cubic km under BAU, whereas under SUS it is projected to fall to 1673 cubic km. In respect of total irrigation water consumption it is expected to increase to 1745 cubic km under CRI as against 1492 cubic km under BAU in the world as a whole; under SUS it is projected to reduce to 1196 cubic km.

Table 5: Total and Irrigation Water Consumption under Business-as-usual, Water Crisis, and Sustainable Water Use Scenarios, 1995 and 2025

Region/Country	**Total Water Consumption (km^3)**				**Total Irrigation Water Consumption (km^3)**			
	1995 baseline estimates	**2025 projections**			**1995 baseline estimates**	**2025 projections**		
		BAU	**CRI**	**SUS**		**BAU**	**CRI**	**SUS**
Asia	1,059	1,206	1,371	949	920	933	1,087	727
China	291	329	385	258	244	231	264	179
India	353	396	446	293	321	332	387	234
Southeast Asia	112	147	175	120	86	92	124	81
South Asia excluding India	174	194	214	157	163	169	193	136
Latin America (LA)	131	170	205	136	88	97	132	86
Sub-Saharan Africa (SSA)	62	93	123	76	50	63	102	47
West Asia/North Africa (WANA)	135	162	160	111	122	137	137	92
Developed countries	440	478	514	426	272	277	304	258
Developing countries	1,358	1,603	1,828	1,246	1,164	1,216	1,440	939
World	**1,799**	**2,081**	**2,342**	**1,673**	**1,436**	**1,492**	**1,745**	**1,196**

Notes: BAU indicates business-as-usual scenario; CRI – water crisis scenario;
SUS – sustainable water use scenario; and km^3 – cubic kilometers
Source: Rosegrant *et.al.*, 2002.

Table 6 presents similar information on water withdrawals under BAU, CRI and SUS scenarios. As evident, water withdrawal patterns directly follow water consumption patterns. Water withdrawals under CRI are significantly higher as compared to BAU levels, whereas SUS levels are substantially lower. For instance, by 2025 total mean water withdrawals are projected to increase to 5231 cubic km under CRI as compared to 4772 cubic km under BAU, whereas under SUS it is expected to be around 3743 cubic km. The country and regional patterns also conform to this general pattern. Information on the ratio of water withdrawals to total renewable water under the three scenarios presented in Table 7 also conform to the patterns indicated earlier, whereby water withdrawals by 2025 are projected to be much higher under CRI as compared to BAU levels, and lower under SUS. For instance, the ratio of water withdrawals to total renewable water for the world as a whole is projected to rise to 0.11 under CRI as against 0.10 under BAU, whereas under SUS it will be around 0.08. For Asia, these ratios are 0.23, 0.20 and 0.16 under CRI, BAU and SUS scenarios respectively. Especially for Asia as a whole and Asian countries/regions such as China and India, South Asia (excluding India), the ratio of water withdrawals to total renewable water are projected to be much higher under CRI as compared to BAU levels, and much lower under SUS.

Table 6 : Total Mean Water Withdrawal under Business-as-usual, Water Crisis, and Sustainable Water Use Scenarios, 1995 and 2025

Region/Country	**Total Mean Water Withdrawal (km^3)**			
	1995 baseline estimates	**2025 Projections**		
		BAU	**CRI**	**SUS**
Asia	2,165	2,649	2,943	2,039
China	679	846	978	644
India	674	815	889	602
Southeast Asia	203	287	323	222
South Asia excluding India	353	421	449	335
Latin America (LA)	298	410	477	302
Sub-Saharan Africa (SSA)	128	214	247	173
West Asia/North Africa (WANA)	236	297	289	199
Developed countries	1,144	1,265	1,342	1,085
Developing countries	2,762	3,507	3,889	2,659
World	3,906	4,772	5,231	3,743

Notes: BAU indicates business-as-usual scenario; CRI – water crisis scenario; SUS – sustainable water use scenario; and km^3 – cubic kilometers

Source: Rosegrant *et.al.*, 2002.

Table 7: Ratio of Water Withdrawal to Total Renewable Water under Business-as-Usual, Water Crisis, and Sustainable Water Use Scenarios, 1995 and 2025

Region/Country	**1995 baseline estimates**	**2025 Projections**		
		BAU	**CRI**	**SUS**
Asia	0.17	0.20	0.23	0.16
China	0.26	0.33	0.38	0.25
India	0.30	0.36	0.39	0.26
Southeast Asia	0.04	0.05	0.06	0.04
South Asia excluding India	0.18	0.22	0.23	0.17
Latin America (LA)	0.02	0.03	0.03	0.02
Sub-Saharan Africa (SSA)	0.02	0.04	0.05	0.03
West Asia/North Africa (WANA)	0.69	0.90	0.88	0.61
Developed countries	0.09	0.10	0.10	0.08
Developing countries	0.08	0.10	0.11	0.08
World	**0.08**	**0.10**	**0.11**	**0.08**

Notes: BAU indicates business-as-usual scenario; CRI – water crisis scenario; SUS – sustainable water use scenario; and km^3 – cubic kilometers

Source: Rosegrant *et.al.*, 2002.

Information regarding the sector wise projected water consumption under the three scenarios are presented in Table 8. As stated earlier, the irrigation sector accounts for bulk of total water consumption for the countries and regions under review. While irrigation water consumption by the year 2025 is envisaged to increase under CRI as compared to BAU levels, under SUS all countries and regions report a decline in irrigation water consumption. Interestingly in the case of domestic water use, water consumption is envisaged to fall under CRI as compared to BAU levels; however, under SUS although domestic water consumption is higher as compared to CRI levels it is lower than under BAU. This is true for the world as a whole, developed and developing countries as well as Asia and Asian countries such as China and India. These differences arise because of the following facts. Under SUS domestic water supply for the disadvantaged sections is expected to improve through the universal extension of household water connections, while the initially connected households reduce consumption in response to higher prices and improved water savings technology (Rosegrant et al, 2002). While in rural areas there is an increase in overall per capita domestic water consumption compared with BAU levels, in urban areas overall per capita domestic water consumption declines because of the greater weight of initially connected households in urban areas (Rosegrant et al, 2002). Under CRI, however, domestic water supply condition aggravates because the proportion of population in households connected to water supply declines sharply compared with BAU. Per capita demand under CRI for both connected and unconnected households is envisaged to be significantly lower than under BAU in both rural and urban areas of most regions in both developed and developing countries (Rosegrant et al, 2002). Industrial water demand is also envisaged to reduce under SUS as compared to BAU levels, whereas under CRI it is expected to substantially increase. This is true for both developed and developing countries as well for Asia and Asian countries such as China and India. Technological improvements in water use and recycling and increased water prices that induce reductions in demand account for this reduced industrial water consumption under SUS (Rosegrant et al, 2002). Under CRI, weakened incentives and regulations, and lower investment in technology result in increased industrial water consumption as compared to BAU levels as more water is required to produce a unit of output (Rosegrant et al, 2002).

Table 8: Sectorwise Water Consumption Projection for 2025 under BAU, CRI and SUS Scenarios

Countries/Regions	1995 Baseline Estimate	2025 Projects		
		BAU	CRI	SUS
		Total Irrigation Water Consumption (tm^3)		
Asia	920	993	1087	727
China	244	231	264	179
India	321	332	387	234
South East Asia	86	92	124	81
South Asia excluding India	163	169	193	136
Developed Countries	272	277	304	258
Developing Countries	1164	1216	1440	939
World	1436	1492	1745	1196
		Domestic Water Consumption (km^3)		
Asia	79.1	156.7	113.0	143.9
China	30.0	59.4	42.3	54.3
India	21.0	40.9	27.7	42.0
South East Asia	13.9	30.4	23.6	23.8
South Asia excluding India	7.0	16.2	11.1	15.3
Developed Countries	58.7	68.6	62.8	65.8
Developing Countries	110.6	221.0	159.7	198.7
World	169.3	289.6	222.5	264.5
		Industrial Water Consumption (km^3)		
Asia	48.9	92.6	148.5	55.1
China	13.2	32.1	74.8	18.5
India	7.3	16.0	23.1	9.8
South East Asia	11.5	21.3	23.2	11.6
South Asia excluding India	1.9	4.7	5.7	2.6
Developed Countries	96.6	115.7	133.2	85.6
Developing Countries	62.9	123.8	186.4	69.1
World	159.5	239.5	319.6	154.6

Note: BAU, CRI and SUS refer earlier Table
Source: Rosegrant *et.al.*, 2002

Water Pricing

Increasing demand for water owing to rapid population growth, urbanization and industrialization, and increasing water scarcities and pollution pose a major challenge to many countries. Meeting the increasing demand for water as well as promoting sustainable use and management of water resources is, therefore, an important objective of both developed and developing countries. In many developing countries including

Asian countries irrigation and domestic water services are highly subsidized; consequently water tariffs or prices are low or near zero especially in the agricultural sector or do not cover at least the operation and maintenance costs. Consequently there is no incentive for water managers, farmer-irrigators and urban water consumers to conserve water that is overused and wasted (Rosegrant and Cline, 2002). Because of its key role in managing water demand and augmenting water supply, water pricing is an important policy instrument for creating incentives to conserve and allocate water efficiently (Saleth, 2001). By providing financial justification for developing additional supplies from conventional and unconventional sources, pricing policy can make more water available to users (Saleth, 2001). Financially water pricing is the main mechanism for cost recovery. Economically it signals the scarcity value and opportunity cost of water and guides allocation decisions within and across water sub sectors. The financial function requires water rates to cover the cost of supplying water to users. The supply cost is usually calculated by adding the operation and maintenance costs and the capital costs of constructing the system. But full cost recovery also requires water rates to reflect the long-term marginal cost (the cost of supplying an additional unit of water including the social costs of externalities (Saleth, 2001). The main objectives of water pricing, therefore, include: (1) creation of incentives for efficient water use, (2) cost recovery in the water sector, and (3) financial sustainability of urban water supply systems and irrigation, including the ability to raise capital for expansion of services to meet future demand (Rosegrant and Cline, 2002). Implementing water sector reforms and especially raising water tariffs so that at least they cover operational and maintenance costs and also raise adequate funds for expanding water infrastructure is not an easy task. Many governments lack the political will to implement such reforms. There are powerful interest groups and lobbies such as farmers groups, urban consumers, political parties, etc who work against such reforms. Compulsions of electoral politics such as in India also results in political parties competing with each other to announce freebies such as free water, free power when elections are on which thwarts any attempt at water and power reforms. Added to that there is also concern about the need for making water affordable especially for the poor and vulnerable sections. The poor, however, do not benefit from urban water services and hence water subsidies mostly benefit the better off sections. Further water has been treated as a free good traditionally and also as a basic right and hence raising water tariffs as part of overall water sector reforms poses further problems.

Water tariffs or rates are usually fixed on volumetric basis based on the quantity of water used or flat rate based on the area irrigated or households benefited. Volumetric pricing is conducive to creating incentives for efficient allocation and use, but the cost of establishing volumetric water delivery structures is often prohibitive, especially in large and spatially spread surface irrigation systems serving many small holders (Saleth, 2001). As a result area based fixed rates are dominant in most irrigation systems. However, volumetric water rates are widely used in many urban water supply systems.

In the following sections a review of the water tariffs or prices for selected countries in Asia and other regions is made. Table 9 presents data on water price ranges across countries for the agricultural, domestic and industrial sectors during the late 1990s.As evident, both fixed and variable system of levying water tariffs is prevalent in the countries under review. The table shows wide variations in the water rates prevailing in different countries including Asian countries. For instance in the agricultural sector the fixed water prices range from USD 0.16 to 27.47 per ha per year or season in India, to around USD 246 per ha per year or season in Japan. For other countries listed in the table the water prices range between USD 0.75-2.27 per ha per year or season in Australia to USD 0.96-164.48 per ha per year or season in Spain. There is no consistent pattern in the water price ranges between developed and developing countries with rates in some developing countries (e.g., Namibia) being relatively high as compared to developed countries and water rates in some developed countries (e.g. Canada) being relatively low as compared to some developing and developed countries. If we compare the water price ranges across sectors too we find no consistent pattern. One, however, finds that for the countries under review while in the agricultural sectors fixed water rates are more prevalent, in the domestic and industrial sectors variable water rates are more prevalent. In the domestic sector water rates are generally higher in the developed countries (see for e.g., Japan, Canada, France, and U.K.) as compared to developing countries (e.g., India, Pakistan, and Tanzania). A similar trend is seen with respect to water rates in the industrial sector. Generally it is believed that water tariffs or rates are highest in the industrial and domestic sectors and least in the agricultural sector. For instance, Saleth (2001) notes that “ the industrial and power sectors within a country usually pay the highest water rates and receive a higher, more costly level of service through out the year, as do domestic users. Agriculture pays the least, but also receives the lowest level of service”. However, the table suggests that this is not necessarily true and in a number of countries domestic and industrial water rates are lower than those in the agricultural sector. However, while the above sheds light on the water rates or price ranges prevalent in a cross section of countries in Asia and other regions this does not say anything about whether these water rates or prices cover the cost of water services etc. For any meaningful analysis about the water rates or prices across countries and sectors, these need to be related to the cost of water services. However, data on this aspect is lacking.

Table 9: Water Price Ranges in US Dollars for Agriculture, Domestic and Industrial Sectors in Selected Countries (1996 or 1997 constant USD)

Country	**Agriculture**		**Domestic**		**Industry**	
	Fixed (per ha per year or season)	**Variable (per cubic meter)**	**Fixed (per ha per year or season)**	**Variable (per cubic meter)**	**Fixed (per ha per year or season)**	**Variable (per cubic meter)**
<u>Asia</u>						
India	0.16-27.47	-	0.82	0.01-0.08	5.49	0.14-0.29
Japan	246	-	-	1.56	-	-
Korea, Republic	-	-	-	0.27	-	-
Pakistan	1.49-5.80	-	0.25-1.63	0.06-0.10	-	0.38-0.97
Taiwan	23.30-213.64	-	-	0.25-0.42	-	-
<u>Other Countries</u>						
Australia	0.75-2.27	0.02	9-162	0.23-0.54	-	7.82
Brazil	3.5	0.004-0.03	-	0.40	-	-
Canada	6.62-36.65	0.002	-	0.34-1.36	-	0.17-1.52
France	-	0.11-0.39	-	0.36-2.58	-	0.36-2.16
Germany	-	-	-	1.69	-	1.02-3.70
Italy	20.98-78.16	-	-	0.14-0.82	-	-
Madagascar	6.25-11.25	-	0.08-0.25	0.39	-	-
Mexico	33-60	-	-	-	-	0.08-0.35
Namibia	53.14	0.004-0.03	1.54-4.28	0.22-0.45	-	-
Spain	0.96-164.48	0.0001-0.03	-	0.0004-0.005	-	0.0004-0.005
Sudan	4.72-11.22	-	1.67-3.33	0.08-0.10	1.67-3.33	0.08-0.10
Tanzania	-	0.26-0.40	-	0.06-0.24	-	0.26-0.40
Turkey	-	12.00-80.00	-	-	-	-
Uganda	-	-	-	0.38-0.59	-	0.72-1.35
U.K.	-	-	152-171	0.01-0.02	-	-
U.S.A.	-	0.01-0.04	-	-	-	-

Note: For Japan, Korea, Germany, Mexico, Sudan and Turkey prices are in July 1997 constant USD; for remaining countries prices are in 1996 constant USD

Source: Dinar, 2000.

Information on the State wise water rates for domestic and industrial users in India are furnished in Table 10. As evident, the water rates for domestic and industrial users vary widely across states in India. For instance, in the case of domestic water supply the rates and water levy systems differ from state to state. While in some states or union territories water rates are fixed on the basis of water connection or number of taps (e.g. Sikkim) in others a flat monthly rate irrespective of the volume of water consumed (e.g. Meghalaya, Goa) and still in others volumetric based water rates are levied (e.g. Bihar, Gujarat, Madhya Pradesh, Orissa, Punjab, Rajasthan, etc). However, these volumetric based water rates vary widely across states from around Rs 3 per 1000 cubic metre in Gujarat and Himachal Pradesh to Rs 600 per 1000 cubic metre in Bihar. Some states also have a graded system whereby the water rates levied vary progressively depending upon the volume of water consumption i.e. the first block carries a lower water rate, the next block of water consumed a higher rate and so on (for e.g., in Kerala, Haryana). In the case of industrial water supply too the water rates vary widely across states in India from over Rs 35 per 1000 cubic metre in Rajasthan to over Rs 3107 per 1000 cubic metre in Madhya Pradesh. Another feature to observe is that in some states these water rates for domestic rates were last revised three or four decades ago, for instance, in 1982 or 1983 in Gujarat, Madhya Pradesh and Rajasthan.

Table 10: State-wise Water Rates for Domestic and Industrial Water in India

(Rs. Per Cu.m.)

States/UTs	Year # (Last Revision)	Domestic Water	Industrial Water Supply
Andhra Pradesh	1.7.96	Rs.40/-	Rs.1000/- Monthly minimum charge
Arunachal Pradesh	**	**	**
Assam	-	-	-
Bihar	14.11.95	Rs.660/- 1000 Cu.Metre	Rs.600/-, 1000 Cu.Metre
Goa	1.1.98	Rs.15/-	Rs.7/- per Cu.m. upto 100 Cu.Metre & Rs.91/- per Cu.m. above 100 Cu.m.
Gujarat	1.4.83	Rs.3/- 1000 Cu.Metre	Rs.40/- per 1000 Cu.Metre
Haryana	27.7.94	N.A.	Rs.776.75 per 1000 Cu.Metre
Himachal Pradesh	6.8.92	First 5.71 Cu.m. @ 90 paise per 1000 Cu.Metre Subsequent 5.71 Cu.m. @ Rs.1.58 per 1000 Cu.M. and subsequent 11.41 Cu.m. @ Rs.2.48 per 1000 Cu.M.	N.A.
Jammu & Kashmir	-	-	-
Karnataka	-	-	-
Kerala	1.6.94	Rs.17/- to Rs.132/-	Rs.115/-
Madhya Pradesh	1.4.83	Rs.42.38/1000 Cu.m.	Rs.3107.70 per 1000 Cu.M.
Maharashtra	1.7.93	(i) Dam built on river pond Rs.0.50/13.93 Cu.m. (ii) Water stored in tank Rs.100/13.93 Cu.m. (iii) Water not stored in Tank Rs.1.50/13.93 Cu.m.	-
Manipur	-	-	-
Meghalaya	-	No water rates are enforced	
Mizoram	Jun-92	Rs. 75/- per month from each house having water connection	-
Nagaland	-	Water rates for drinking water and industrial use have to be fixed in terms of taps, size of pipes, etc. by PHE Dept. of Govt. of Nagaland	
Orissa	18.7.98	Rs.105.94 per 1000 Cu.M.	Rs.132.16 per 1000 Cu.M.
Punjab	1993-94*	Rs.35.71 per 1000 Cu.M.	357.14 for brick mating or stone masonary

Table 10: (contd…)

States/UTs	Year # (Last Revision)	Domestic Water	Industrial Water Supply
Rajasthan	Mar-82	Rs.28.25 per 1000 Cu.M.	Rs.35.31 per 1000 Cu.M.
Sikkim	N.A.	Household having upto 5 taps Rs.21/- per month for additional upto 20 taps @ Rs.0.50 per tap and beyond 20 taps @ Rs.1.50 per tap	Upto Rs.25.07 Cu.m. per month Rs.21/- and for every additional 6.25 Cu.m. @ Rs.1/- per month
Tamil Nadu	1982*	No rates	Rs.3000 per 1000 Cu.M.
Tripura	1996*	(i) For rural water supply Rs.5/- per month against each domestic connection (ii) 3% of annual rental valuation of the holding in case of holding not having domestic comet	-
Uttar Pradesh	-	N.A.	N.A.
West Bengal	-	N.A.	N.A.
Andaman & Nicobar Islands	N.A.	(i) 1/2* tap connection with overhead tank nominal size Rs.20/- per month (ii) Taps shared by two and more than six consumers when common taps are provided to Govt. qrs Rs.2/- per Allottee	
Dadra & Nagar Haveli	1996*	Rs.5.50 per connection per month	On Rs.8.50 per connection per month
Daman & Diu	1994	(i) Rs.0.70 per Cu.m. per month upto 10 Cu.m. per month (ii) Rs.1.50 per Cu.m. over 10 Cu.m. per month	Rs.4.00 per Cu.m.
Delhi	1.4.1994	Rs.30 per month per dweller Rs.25 per 1.39 Cu.m. on unit including sewage chart water charge as sewages	
Pondicherry	1990-91*	Rs.500/- per 1000 Cu.M.	Rs.1,500/- per 1000 Cu.M. (commercial)
Chandigarh	1.4.1995	(i) 1st 15 Cu.m. = 0.70 (ii) upto 30 Cu.m. = 1.30 (iii) above 30 Cu.m. = 1.80	Rs.3.00
Lakshadweep	-	No water rates are enforced	

Note: #: the data shown are the dates of last revision in the respective state
*: relates to the date of State Government's Notification
**: No. water rates enforced in the State

Source: Pricing of Water in Public System in India, Information Systems Organization Water Planning & Projects Wing, Central Water Commission.

The agricultural sector and within that the irrigation sector accounts for bulk of water consumption, the rest being accounted by the livestock sector. With demand for food rising due to population growth and rising incomes, demand for water for raising crop output is also rising. Improving water use efficiency is, therefore, an important policy objective. In this context it would be interesting to see as to how far irrigation costs are being recovered. Table 11 furnishes information on the irrigation, fertiliser and pesticide costs for irrigated rice in six project sites of a joint IRRI-National Agricultural Research System projects studied by the International Rice Research Institute in Manila, Philippines. As is as well known rice is a heavily irrigated crop and rice is the major crop in many Asia countries. The data presented in the table cover a cross section of countries in Asia. The table shows wide variation in the irrigation cost across the six countries ranging from zero in India and Thailand to USD 25 per ha per crop in China. As a proportion of gross revenues the irrigation costs range from zero percent in India and Thailand to 2.5 percent in China. Thus even among Asian countries we find wide disparities with irrigation costs being low or zero. From the viewpoint of improving water use efficiency at least the operation and maintenance costs need to be recovered. Although full cost recovery may be desirable from the long-term view point this may be impractical and may also conflict with equity concerns since it may put water out of the reach of the poor and vulnerable sections.

Table 11: Irrigation, Fertilizer and Pesticide Costs for Irrigated Rice in Six Joint IRRI-National Agricultural Project Sites in Six Asian Countries, 1999

Site/Country	Irrigation Cost (USD per ha per Crop)	Irrigation Cost as % of Gross Revenues	Fertilizer Cost as % of Gross Revenues	Pesticide Cost as % of Gross Revenues
India	0	0.0	7	0.0
Vietnam	6	1.0	13	4.1
China	25	2.5	12	3.0
Philippines	13	1.5	7	2.2
Thailand	0	0.0	10	6.9
Indonesia	4	0.5	5	4.3

Note: These data pertain to six project sites of the Joint IRR-National Agricultural Research Systems Projects. These project sites are as follows:
India – Aduthurai, Grand Anicut Dam, Cauvery Delta, Tamil Nadu
Vietnam – Cuu Long, Cantho, Mekong Delta
China – Jinhua, Zhejiang
Philippines – Nueva Ecija, Upper Pampanga River Irrigation System, Central Luzon
Thailand – Suphan Bunr, Pho Phaya Irrigation System, Central Plan
Indonesia – Sukamandi, Jatiluhur Irrigation System, West Java

Source: Valencia *et.al.,* 2001

Information about the maximum and minimum water rates for selected crops across different states in India is presented in Table 12. Even within India one comes across wide variations in the water rates for the same crop. For instance for paddy (or rice) the maximum water rates ranged from Rs 49.4 per ha in Tamil Nadu to over Rs 2772 per ha in Orissa; the minimum water rate ranged between Rs 37 per ha in Kerala, Tamil Nadu and West Bengal to over Rs 516 per ha in Orissa. In the case of wheat the maximum water rates ranged between over Rs 54 per ha in Karnataka to over Rs 831 in Orissa; and the minimum water rates ranged between Rs 12 to 111 per ha. In the case of sugarcane, which is also heavily irrigated, the maximum water rates ranged between over Rs 49 per ha in Tamil Nadu to over Rs 2495 in Orissa; and the minimum water rates ranged between Rs 51 to 1000 per ha. In the case of other crops the maximum water rates ranged between Rs 33 to over Rs 1109 per ha for cotton, between Rs 56 to Rs 1050 per ha for oilseeds and Rs 51 to Rs 300 per ha for pulses; The minimum water rates for these crops ranged between Rs 36 to Rs 300 per ha for cotton; Rs 32 to Rs 247 per ha for oilseeds and Rs 24 to Rs 247 per ha for pulses. Thus one finds wide variations in the maximum and minimum water rates charged for different crops across different states in India. What is more perplexing to note is that in some states the water rates were last revised three or four decades ago i.e. in 1962 (e.g. Tamil Nadu) or 1981 or 1982 (e.g. Rajasthan and Gujarat).

That water rates are highly subsidized especially in developing countries including Asian countries is a well-known fact. Leave alone capital costs, these rates don't even cover the operation and maintenance costs, as noted earlier. In fact if one considers the rates charged by private water vendors as the shadow price of water there is wide variation between the water rates levied by public bodies and the shadow price of water. Table 13 presents the ratio of water prices charged by private vendors to prices charged by public utilities in selected cities in Asia and other regions. The ratio of private vendor to public utility water prices varies from 4-60:1 in Jakarta, Indonesia to 28-83:1 in Karachi, Pakistan. In other regions these ratios range from 4.9:1 in Kampala, Uganda to 100:1 in Nouakchott, Mauritania. These clearly show how highly subsidized water supplied by public utilities is as compared that from private vendors.

Table 12 : State-wise Water Rates for Paddy, Wheat, Sugarcane, Cotton, Oilseeds, Pulses in India

(Rs./Ha.)

States	Year $ (Last Revision)	Paddy		Wheat		Sugarcane		Cotton		Oilseeds		Pulses	
		Maximum	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**
Andhra Pradesh	01/07/1996	494.22	247.11	-	-	494.22	247.11	494.22	247.11	494.22	247.11	494.22	247.11
Bihar	14-11-95	247.11	86.49	148.27	111.2	296.53		N.A.	N.A.	98.84	74.18	98.84	74.13
Haryana	20-07-95	89.7	59.8	74.87	12.11	296.53	89.66	74.87	36.08	59.8		59.8	
Kerala	01/07/1994	90	37	-		-	-	-	-	-	-	-	-
Madhya Pradesh	01/10/1992	59.3	54.36	61.78	14.83	296.53		92.67	59.31	59.31	44.48	42.01	
Maharashtra	01/07/1990	750	100	175	100	1750	1000	1050	300	1050	200	300	100
Orissa	00-07-97	2772.57	516.16	831.77	33.3	2495.32	100.08	1109.03	55.6	-	-	-	-
Punjab	14-02-97	**	**	**	**	**	**						
Tamil Nadu	01/07/1962	49.42	37.07	-	-	49.42		61.78	48.42	-	-	-	-
Uttar Pradesh	18-09-95	287	40	287	40	474	99	33	114	212	40	212	40
West Bengal	00-01-93	123	37.06	49.03		-	-	-	-	74.13		-	-
Rajasthan	00-03-82	98.84	56.84	74.13	32.12	143.32*	51.89*	88.96	44.48	56.84	32.12	51.89	24.71
Gujarat	15-06-81	125	110	110		830	830	200	100	200	100	60	50
Karnataka	01/07/1985	98.84	86.49	54.36		556	370.66	98.84		59.31		37.07	

Note: *: For Perennial channels & past 1952 Irrigation works; $: the date shown are the dates of last revision in respective states; **: water rates have been abolishing by the State Government

Source: Pricing of Water in Public System in India, Information Systems Organization Water Planning & Projects Wing, Central Water Commission.

Table 13: Ratio of Water Prices charged by (Private) Vendors to Prices charged by Public Utilities in Selected Cities

Region/Country	City	Ratio
Asia		
Bangladesh	Dacca	12-25:1
Indonesia	Jakarta	4-60:1
	Surabaya	20-60:1
Pakistan	Karachi	28-83:1
Africa		
Cote d'Ivoire	Abidjan	5:1
Kenya	Nairobi	7-11:1
Mauritania	Nouakchott	100:1
Nigeria	Lagos	4-10:1
	Onitsha	6-38:1
Togo	Lome	7.10:1
Uganda	Kampala	4.9:1
North America		
Haiti	Port-au-Prince	17-100:1
Honduras	Tegucigalpa	16-34:1
South America		
Ecuador	Guayaquil	20:1
Peru	Lima	17:1

Source: adapted from Bhatia and Falkenmark (1993) *vide* Rosegrant and Cline, 2002, p.7.

A World Bank Study (2002) on the water tariff structure in six large South Asian cities in India, Nepal, Sri Lanka and Bangladesh are quite revealing. Table 14 that summarises the findings of this study show that the service area and the population of the six cities studied vary widely. Both measured and unmeasured systems are in place for charging domestic water. The level of metering of domestic connections varies from less than 5 percent in Chennai and 10 percent in Bangalore (both in India) to 97 percent in Colombo (Sri Lanka). Even within India one comes across wide variations. For instance, unlike in Chennai and Bangalore where the level of metering ranged between less than 5 to 10 percent. Hyderabad reported the level of metering to be as high as 90 percent. Another aspect to be noted was the proportion of installed meters that were working. This ranged from 40 percent in Hyderabad to 60 percent in Chennai and Kathmandu, to around 100 percent in Bangalore. The water tariffs levied in these six states varied according to the volume of water consumed. These blocks ranged from just 2 in Kathmandu to 6 in Colombo. The size of the initial block too varied across the six cities from 10 cubic metres in Chennai, Kathmandu and Colombo to 25 cubic metres in Bangalore. The minimum water tariffs in these six cities ranged from USD 0.53 per month in Kathmandu and USD 0.61 per month in Colombo to USD 1.38 per month in Bangalore. The cost of the highest block of water consumed ranged from a low of USD 0.07 per cubic metre in Dacca (Bangladesh) and USD 0.12 per cubic metre in Kathmandu to USD 0.70 per cubic meter in Bangalore.

Thus even within the South Asian region ones comes across wide variations in the water tariffs for domestic users.

Table 14: Water Tariff Structure in Six Large South Asian Cities - 2001

Item	**India**			Nepal	Srilanka	Bangla-desh
	Chennai	**Bangalore**	**Hyderabad**	**Kathmandu**	**Colombo**	**Dacca**
Service Area (km^2)	174	368	200	50	110	360
Population (Million)	5.7	5.3	4.7	1.1	1.0	9.5
System used for charging domestic water:						
Measured	Yes	Yes	Yes	Yes	Yes	Yes
Unmeasured	Yes	No	Yes	Yes	Yes	Yes
Water Tax	Yes	No	No	No	No	No
Level of Metering – Domestic Connections	<5%	10%	90%	80%	97%	75%
% of Installed Meters that are working	About 60	About 100	40	60	NA	NA
No. of Blocks in IBT Structure	4	5	4	2	6	NA
Size of Initial Block (m^3)	10	25	15	10	10	NA
Cost of Highest Block (USD/m^3)	0.53	0.70	0.29	0.12	0.27	0.07
Minimum Payment (USD per month)	1.06	1.38	1.17	0.53	0.61	Nil

Source: World Bank (2002)

The same study also sheds light on the water tariffs and the cost of water production in these six South Asian cities. For estimating the cost of water production or supply the study took into account the operation and maintenance costs, all overheads and capital charges excluding future investments (i.e. the long run marginal costs of supplying water will be higher). As evident from Table 15, the cost of water produced varies widely across the cities studied from USD 0.08 per cubic metre in Dacca to USD 0.34 in Bangalore. What is most interesting to observe is that the water tariffs charged in the lowest two domestic tariffs blocks were well below the unit cost of water production in all the cities surveyed except perhaps in Dacca where the water tariff (USD 0.07) almost covered the cost of production (i.e. USD 0.08). This means that water is heavily subsidised and does not even cover the cost of water services provided. It is, of course, possible that cross subsidization prevails where higher end water consumers may subsidise the lower end water consumers by paying higher water tariffs as compared to lower end water consumers.

Table 15: Water Tariffs and Production Costs in Six Large South Asian Cities (USD per m^3 in 2001)

Item	**India**			Nepal	Srilanka	Bangla-desh
	Chennai	**Bangalore**	**Hyderabad**	**Kathmandu**	**Colombo**	**Dacca**
Production Cost of Water (Estimates)*	0.27	0.34	0.26	0.17	NA	0.08
Lowest Domestic Tariff Block	0.05	0.07	0.07	0.05	0.01	0.07
Second Lowest Domestic Tariff Block	0.21	0.14	0.07	0.12	0.02	0.07

Note: Cost of water production was estimated as operation and maintenance costs, all overheads and capital charges (capital charges in Bangalore, Dhaka and Kathmandu relate to debt service charges and in Chennai, Hyderabad and Colombo capital charges relate to depreciation). The production cost figures are based on historical data and do not take into account the large future investment required in most of these cities, which will mean that long-run marginal costs will be much higher.

Source: World Bank (2002)

Table 16 gives more detailed information about the domestic water consumption, tariffs and cost recovery for different water tariff blocks in two major Indian cities, i.e. Bangalore and Hyderabad. As seen from the table, in Bangalore city there are five water tariff blocks based on the quantity of water consumption ranging from 0-25 cubic metre to above 100 cubic metres; in Hyderabad there are three such blocks with the lowest being 0-15 cubic metres and the highest above 25 cubic metres (there is one more block above 500 cubic metres but this is accounted by non-domestic users). Bulk of the domestic water supply connections in the two cities fall in the lowest two tariff blocks and these two tariff blocks also account for bulk of the water sold by the city public utilities i.e. Bangalore Water Supply and Sewage Board (BWSSB) and Hyderabad Metro Water Supply and Sewage Board (HMWSSB). For Bangalore city the water tariffs for the different tariff blocks range from USD 0.07 per cubic metre to USD 0.70 per cubic metre whereas in Hyderabad these range from a flat rate of USD 1.17 per month in the lowest tariff block to USD 0.12 per cubic metre for the highest tariff block. Assuming the cost of water production to be around USD 0.34 per cubic metre, the table shows that cost recovery for the lowest tariff block in Bangalore is just 21 percent and 41 percent in the next block; in the higher blocks the cost recovery ranges from 118 percent to 206 percent in the highest tariff block. This clearly shows that higher end users are subsidizing the lower end consumers. However, the two lowest tariff blocks account for bulk of the domestic water connections and water sold and overall it appears that water supply services by the BWSSB is mostly subsidised. In the case of Hyderabad city too the cost recovery ranges from 30 to 48 percent for the tariff blocks under review. It is thus obvious that in both cities the water tariffs charged by the public utilities don’t even cover the cost of production or supply.

Table 16: Domestic Water Consumption, Tariff and Cost Recovery in each Tariff Block in Bangalore and Hyderabad Cities (2001)

Tariff Blocks (m^3)	Number of Connections billed within the Block	% of Connections	Daily Quantity Sold (MLD)	% of Daily Quantity Sold (MLD)	Tariff (USD/ m^3)	Cost Recovery (Cost of Production = USD 0.34/m^3) %
	Bangalore					
0.25	171,800	65.7	72	36.5	0.07	21
25-50	72,020	27.5	81	41.1	0.14	41
50-75	14,314	5.5	28	14.2	0.40	118
75-100	2,525	1.0	6	3.0	0.55	162
>100	822	0.3	10	5.1	0.70	206
TOTAL	261,481	-	197	-	-	-
	Hyderabad					
0-15	231,503	70.0	86	51.0	Flat Rate 1.17	Not possible to estimate
15-25	65,025	20.0	42	25.0	0.07	30
Above 25	33,600	10.0	41	24.0	0.12	48
TOTAL	330.128	100	169	-	-	

Note: 1. Data for Bangalore pertain to Bangalore Water Supply and Sewerage Board (BWSSB) and for Hyderabad to Hyderabad Metro Water Supply and Sewerage Board (HMWSSB).

2. Water Production cost includes operation and maintenance costs, depreciation and current debt service only; it does not include future investment costs.

3. In Hyderabad, there is a fourth Tariff Block of over 500 m^3 but the study assumed that no domestic consumers fall into this block.

Source: World Bank (2002).

Water Productivity

Agriculture and especially the irrigation sector accounts for bulk of the water consumption in most regions, and more so in Asia. For instance, agriculture’s share in annual freshwater withdrawals for the world as a whole is about 71 percent, as compared to 9 percent for the domestic and 20 percent for the industrial sectors. In most Asian countries agriculture’s share in annual freshwater withdrawals exceeds 70 to 90 percent; in fact in most South and Southeast Asian countries agriculture’s share exceeds 90 percent. However, with growing water scarcities and growing competition for available water from the domestic, industrial and environmental sectors as well as the prohibitive costs of future irrigation investments, etc economising on water use and improving water use efficiency especially in agriculture assumes importance. In this context attention needs to be focused on improving crop yields per unit of water input and reducing water losses

Rice, which is the staple food for nearly half of the world's population especially in Asia, is a heavily irrigated crop. More than 90 percent of the world's rice is produced and consumed in Asia (Barker and Herdt, 1985, vide Guerra et al, 1998). In fact more than 80 per cent of the developed freshwater resources in Asia are used for irrigation purposes and about half of the total irrigation water is used for rice production (Bhuiyan, 1992 vide Guerra et al, 1998). The abundant water environment in which rice grows best differentiates it from all other important crops (Guerra et al, 1998). However, with water becoming increasingly scarce and with agriculture's share of water being projected to decline faster because of increasing competition for available water from the urban, industrial and environmental sectors, economising on water use in agricultural production is an important objective. For instance, it is noted that in many Asian countries per capita availability of freshwater declined by 40-60 percent between 1955 and 1990 and is expected to decline further by 15-54 percent over the next 35 years (Gleick, 1993 vide Bouman and Toung, 2000). Rice being a water intensive crop, it is believed that there is tremendous scope to economise on water use in rice production and thereby improve water use efficiency and water productivity. Consequently, a lot of resources are being invested on research to find ways for improving water use efficiency and water productivity in agriculture and especially of water intensive crops like rice.

Before discussing about crop water productivity we may briefly deal with the issue of irrigation efficiency in general. Irrigation efficiency is generally defined as the ratio of the amount of water that is required for an intended purpose divided by the total amount of water diverted to a spatial domain of interest (Guerra et al, 1998). The domain may refer to a farm, system or basin level. Overall irrigation efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be subdivided into conveyance efficiency, field channel efficiency and field application efficiency. Water losses could occur at different levels i.e. at the farm, system or basin level. Reducing water losses at each stage and overall water loss is an important goal for saving water and improving water use efficiency. Table 17 gives an idea of the overall irrigation efficiency of selected irrigation systems in some Asian countries. It is interesting to note that the overall irrigation efficiency of the irrigation systems in four countries under review show large variations. These range from around 30-38 percent in India to 40-65 percent in Indonesia. In Thailand for the irrigation system under review the irrigation efficiency for wet season was 37-46 percent and between 40-62 percent for dry season. If these figures could be taken as indicative of the level of water use efficiency of irrigation systems in Asia it suggests that there is tremendous scope to cut down water losses and improve water use efficiency in irrigated agriculture.

Table 17: Overall Irrigation Efficiency of Selected Irrigation System in Some Asian Countries

Country/Irrigation System	Overall Irrigation Efficiency %	Remark	Source
Indonesia	40-65		Hutasoit, 1991
Malaysia		Command area	
- Kerian Irrigation System	35-45	= 23,560 ha	
Thailand			
- Northern, Maeklong	37-46	Irrigable area	Khao-Uppatun,
Chao Phraya, >12800 ha	40-62	>12,800 ha	1992
		Wet season	
		Dry season	
India			
- Canal system, north India	38		Ali, 1983
- Tungabhadra Irrigation System, Karnataka State	30		Bos and Wolters, 1991

Note: Overall Irrigation Efficiency of an irrigation system is defined as the ratio of water used by the crop to water released at the headworks. It can be subdivided into conveyance efficiency, field channel efficiency and field application efficiency.
Source: Guerra et al, 1998

Rice, as mentioned earlier, is a heavily irrigated crop. Rice grown under traditional practices in medium to heavy textured soils in the Asian tropics and subtropics requires between 700 to 1500 mm of water (Bhuiyan, 1992, vide Guerra et al, 1998). This consists of: (1) land preparation requirement of 150 to 250 mm, (2) water requirement of about 50 mm for growing rice seedlings in the nursery or seedbed before transplanting, and (3) water need of between 500 to 1200 mm (5-12 mm per day for 100 days) to meet the evapotranspiration (ET) demand and unavoidable seepage and percolation in maintaining a saturated root zone during the crop growth period (Guerra et al, 1998). The actual amount of water used by farmers for land preparation is often several times higher than the typical requirement of 150-250 mm. For instance, in the Ganges-Kobadak irrigation project in Bangladesh it is reported that farmers used as high as 1500 mm for land preparation (Ghani et al, 1989, vide Guerra et al, 1998). This may be due to the need for land soaking so as to maintain a wet soil condition to facilitate plowing, harrowing, puddling, and land leveling so that rice seedlings can be easily transplanted (Guerra et al, 1998). In evaluating water productivity one needs to take of the following. Crops require water to satisfy their evapotranspiration (ET) needs. Further during the crop growth the amount of water usually applied to the field is often much more than the actual field requirement. This leads to high surface runoffs. In fact, Seepage and Percolation (S&P) losses are considerable, and according to one estimate S&P accounts for 50-80 percent of the total water input in the field (Sharma, 1989, vide Guerra et al, 1998).

Reducing the amount of S&P losses would help in improving farm water efficiency. It may, however, be noted that water lost at the farm level may seep downstream and be recovered for crop use and hence doesn’t constitute a loss for the irrigation system. Similarly water loss at the irrigation system level may not contribute to losses at the water basin level. These need to be taken note of while discussing about improving water use efficiency and reducing water losses. Further one also needs to take note of the fact that policies for improving water use efficiency and water productivity cannot be considered in isolation from other factors that contribute to crop yield improvements such as better crop varieties and agronomic practices, crop duration etc. The concept of water productivity, therefore, needs to be clearly specified. For instance, there are a number of water productivity concepts such as irrigation water productivity, basin water productivity, transpiration water productivity, etc (cited in Bessembinder et al, 2005). However, a simple definition is to consider the amount of food or crop yield produced per unit volume of water used. Here it is also important to specify the water use components taken into account while assessing water productivity such as evapotranspiration, seepage and percolation, drainage during land preparation and crop growth period, etc, as noted earlier.

Keeping the above points in view we may examine Table 18 that presents the on farm water productivity of rice for three Asian Countries when different components of water inputs are taken into account. These water components are Evapotranspiration (ET), Seepage and Percolation (S&P), and Land Preparation Requirement (LPR). The table shows that rice yields per unit ET varies from 1.61 kg per cubic metre of water used in Philippines to around 0.88-0.89 kg per cubic metre in Malaysia and India. When other water components (i.e. S&P and LPR) are taken into account the rice productivity declines from 1.61 to 0.39 kg per cubic metre of water used in Philippines; similarly from 0.88 to 0.33 kg per cubic metre of water used in Malaysia. The water use efficiency i.e. the ratio of ET to water input shows wide variations for the countries under review. For instance, if the water components ET, S&P and LPR are taken into account the water use efficiency ratios for rice range from 0.22-0.24 in Philippines to 0.35-0.61 in Malaysia. This shows that the on farm water productivity of rice varies considerably across the three Asian countries under review. However, in making such inter country comparisons and drawing possible policy inferences one should not lose sight of the fact that local level conditions under which rice is grown in the different countries vary. For instance, it is noted that East Asian systems including in China have a much higher degree of management and control than those in South and Southeast Asia, and rice cultivation practices are markedly different even within the same region (Guerra et al, 1998).

Table 18: On-Farm Water Productivity of Rice in Kgs per Cubic Meter of Water used when different components of water inputs are taken into account

Location	Rice Description	Water Productivity of Rice with respect to			Source
		ET	ET+S&P	ET+S&P+LPR	
Philippines	West seeded Rice	1.61	0.68 (0.42)	0.39 (0.24)	Bhuiyan et.al, 1995
Philippines	Transplanted Rice	1.39	0.48 (0.35)	0.29 (0.22)	Bhuiyan et.al, 1995
India	-	1.10	0.45 (0.41)	-	Sandhu et al, 1980
Malaysia	Dry season	0.95	0.66 (0.69)	0.58 (0.61)	Kitamura, 1990
Malaysia	Wet season	0.88	0.48 (0.50)	0.33 (0.35)	Kitamura, 1990
India	Continuous flooding	0.89	0.34 (0.36)	-	Mishra et al, 1990
India	Alternate wet and dry	0.89	0.37 (0.42)	-	Mishra et al, 1990

Notes: 1. ET – Evapotranspiration; S&P – Seepage and Percolation; LPR – Land Preparation Requirement.
2. Figures in parenthesis are water use efficiency ratios, i.e., ratio of ET to water input.

Source: Guerra et al, 1998

Bouman and Toung (2000) report the results of experimental trials in two contrasting rice-growing areas, one in the sub tropics of Central Northern India and the other in the tropics of the Philippines. The data set pertains to the period 1966 to 1997, and covers a wide range of experimental conditions in terms of environment (from pots in greenhouses to on-farm fields), rice variety, soil type, hydrology and climatic conditions. The experiments and treatments had two components, one to study the drought effects on rice and the other on the water saving effects on rice yields. Most of the experiments used transplanted rice, while some used direct seeded rice and others both transplanted and direct seeded rice. The water saving experiments included treatments with just saturated soil either continuously or during part of the growing season and alternate wetting/drying treatments. The latter were treatments where irrigation was given only at a certain number of days after ponded water had infiltrated into the soil or after a certain level of soil water potential in the root zone was reached, or after symptoms of soil cracking at appeared. The relationships between water savings and yield reductions were quantified using data of all experiments reporting on water input and yield. Since the experiments spanned a wide range of conditions, yield levels and water inputs were not comparable and hence the study used the relative yields and relative water scarcities that were calculated by normalizing the yields/water inputs obtained in the drought or water saving treatments to the yield/water inputs obtained in the reference treatment (in percent). The reference treatment consisted of continuously ponded water of 5-10 cm depth, which is generally considered as the optimum depth for rice growth. While yield was assessed in terms of rough grain yield water input was assessed as the sum of effective rainfall and irrigation applications from transplanting to harvest, or from sowing to harvest in the case of direct seeding. The vegetative stage of growth was defined as the period from sowing to panicle initiation, and the reproduction stage from panicle initiation to harvest. The study notes that in 93 percent of the cases water input was reduced compared with the continuous 5-10 cm ponded water treatments. The study notes that water productivity i.e. grain yield over water input increased with water savings from the standard practice of continuous 5010 cm ponded water. Water saving irrigation treatments that continuously kept the soil just at saturation, or allowed for only one day soil drying before re-applying a shallow layer of water were effective in reducing water input while maintaining high yield levels of 33 treatments, the mean water savings were 23 percent whereas yield reduction was only 6 percent. The study notes that typically water productivity was 0.2-0.4 g. grain per kg water in India and 0.3-1.1 g. grain per kg water in the Philippines. The relatively higher water productivities in the Philippines as compared to that in India are attributed to the higher yield levels and lower SP rates of the soils. The study also examined the water productivity water input relationship from all experiments. The study notes that the Indian field data reported the highest water inputs, roughly 500-3000 mm, with the lowest water productivities of 0.1-0.6 g. grain per kg water whereas for the Philippines field experiments water inputs were comparatively lower 300-1500 mm and water productivities higher at 0.3-1.4 g. grain per kg water. There were, of course, exceptions with high water productivities of 1.6-1.9 g. grain per kg water with low water input. The study notes that reducing water input from continuous ponded water levels increases water productivity, up to a maximum of 1.9 g. grain per kg water. However, when ponded water depths drop to zero or when soil water potentials in the root zone become negative, yields (i.e. land productivity) get reduced. The overall conclusion of the study is that the most promising option to save water and increase water productivity without decreasing land productivity too much is by reducing the ponded water depth from 5-10 cm to the level of soil saturation. Water savings were on average 23 percent (+ or – 14%) whereas yield reductions were only 6 percent (+ or – 6%). The adoption of such techniques will have implications for irrigation systems because water delivery to the field needs to be very accurate and timely. Farmers operating pumps would likely benefit most from this water-saving irrigation technique. However, most Asian farmers in public irrigation systems have little incentive to reduce water input to their fields since irrigation water is mostly charged on area basis. Volumetric based charging of irrigation may induce farmers to economise and optimize on water use. Although water savings may reduce yields, the water so saved could be used to irrigate more area that can help increase total rice output.

Alternate agronomic and crop management practices such as zero-tillage, bed planting, non-puddled rice culture and laser leveling, etc are being advocated to reduce costs and water use in crop farming as well improve productivity (Gupta et al, 2002, Hobbs and Gupta, 2002). For instance, in the Indo-Gangetic Plains where rice-wheat cropping system is predominant, wheat is usually sown after rice. Traditional land preparation practices for wheat after rice in this region involve as many as 12 tractor passes. But under zero-tillage system farmer sow wheat in a single tractor operation after the rice harvest, planting the seed directly in the rice stubble (CIMMYT, 2002). The practice reportedly saves 75 percent or more of fuel, obtains better yields, uses about half the herbicide, and requires at least 10 percent less water (CIMMYT, 2002). Because zero-tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cut down on subsequent irrigation requirements, it results in considerable water savings. An estimate suggests that changing to a zero-tillage system on one ha of land, besides saving 60 liters of diesel, saves approximately one million liters of irrigation water (CIMMYT, 2002). This also has significant environmental benefits by reducing carbon dioxide emissions. For instance, using a conversion factor of 2.6 kg of carbon dioxide per liter of diesel burned, this represents about a quarter ton less emissions of carbon dioxide per ha which is the major contributor to global warming (CIMMYT, 2002). If zero-tillage system is widely adopted in the rice-wheat system of the Indo-Gangetic Plains it is estimated that if just 5 out of the 12 million ha adopts zero-tillage, it will result in annual diesel savings of nearly 0.3 billion liters- equivalent to a reduction of nearly 800,000 tons in CO_2 emissions each year as well as increase water availability and efficiency in the rice-wheat cropping system in the Indo-Gangetic Plains. It is reported that farmers adopting zero-tillage save around USD 65 per ha in production costs (CIMMYT, 2002). The area under zero-till wheat in India and Pakistan which was estimated at around 3000 ha in 1998-99 is expected to increase to 0.3 million ha by 2001-02 (CIMMYT, 2002). Bed planting is another technique that is being promoted to raise crop productivity and reduce farming costs and inputs. Bed planting is being popularized in wheat cultivation in India and Pakistan, and also being tried in rice cultivation. It is reported that planting wheat on raised beds improves yields, increases fertilizer efficiency, reduces costs and inputs such as herbicides, seeds, an average of 30 percent in terms of water savings and reduce production costs by 25-35 percent (CIMMYT, 2002). All the above resource conserving technologies like bed planting, zero tillage, non-puddled rice culture, etc. when combined with leveled fields help improve water use efficiency (Hobbs and Gupta, 2002).

As stated earlier, resource conservation technologies such as zero-tillage, bed planting and non-puddled rice cultivation along with laser leveling are being promoted with a view to improve crop productivity and water use efficiency as well as reduce costs and water use. This is being tried in the Indo-Gangetic Plains spread across five countries i.e. India, Pakistan, Nepal and Bangladesh in South Asia, by a consortium that includes CIMMYT, IRRI and other national research organizations. The predominant cropping system in the Indo-Gangetic Plains is rice and wheat, as stated earlier. However, the cropping practices vary across this wide expanse. For instance, while in the northwest region rice is mostly irrigated, in Eastern India rice is mostly raised as a rain fed crop. The two crops have contrasting requirements. The total water requirement for wheat varies from 238 mm to 400 mm and for rice from 1144 mm to 1560 mm across different locales in the Indo-Gangetic Plains (Gupta et al, 2002). While rice is commonly transplanted into puddled soils and gets the benefit of continued submergence, wheat is grown in upland well-drained soils having good tilth (Gupta et al, 2002). Transplanting of rice seedlings into puddled soils is an age-old practice and helps to reduce water percolation and in weed control (Gupta et al, 2002). However, puddling degrades the soil and affects the soil conditions for the establishment of the next crop, which is usually wheat in this region. With a view to get a better wheat crop, farmers in the region generally do 6-8 preparatory plowings in rice drying soils to achieve good seed bed (Gupta et al, 2002). However, excessive tillage results in late planting and reduced yields of wheat. Since rice is the major water user, saving water use in rice cultivation is a major goal. Non-puddled rice cultivation is, therefore, being advocated. Evidences from India suggest that a 3-day drainage period in rice cultivation can effect a minimum of 40 percent saving in water with marginal declines in rice yields. Table 19 that presents the relevant data shows that water savings across different states in the Indo-Gangetic Plains in India varied from 40 to 54 percent. In Ludhiana, Punjab the irrigation requirement after a 5-day drainage period was around 96 cm, as against 190 cm per ha under continuous submergence scenario. The corresponding rice yields were 5.2 and 5.5 tonnes per ha respectively. Although there is some reduction in rice yields the water so saved could be diverted to bring more area under cultivation that will help increase total rice (or agricultural) output. Thereby, it can improve food security and meet the expanding food needs due to increasing population and incomes. Zero-tillage also helps in water savings, as stated earlier. Zero-tillage is possible after harvesting rice where the residual moisture is available for wheat germination. In many instances where wheat planting is delayed after harvesting rice farmers have to pre-irrigate their fields before planting; zero-tillage saves this irrigation. Further, water advances quicker in untilled soil than in tilled soil which helps save water (Gupta et al, 2002). Because zero-till wheat takes immediate advantage of the residual moisture from the previous rice crop, as well as cut down on subsequent irrigation, water use is reduced by about 10 cm per ha or approximately 1 mil liters per ha (Gupta et al, 2002). Further there is less risk of water logging and yellowing of the wheat plants after the first irrigation that is common on normal ploughed land (Gupta et al, 2002).

Table 19: Effect of Intermittent Irrigation on Rice Yield and Irrigation Water Requirement at Various Locations in the Indo-Gangetic Plains

Location	Soil Type	Yield (t/ha)				Saving in Irrigation Water ***
		Continuous Submergence	Irrigation after Drainage Period*			
			1 day	3 day	5 day	
Pusa (Bihar)	Sandy loam	3.6 (81)	3.5 (60)	3.3 (46)	2.9 (35)	43
Madhepura (Bihar)**	Sandy loam	4.0 (35)	-	4.0 (16)	4.0 (11)	54
Faizabad (UP)	Silt loam	3.8 (65)	2.9 (42)	-	-	-
Pantnagar (UP)	Silt loam	8.1 (121)	7.6 (112)	7.4 (90)	6.9 (60)	44
Ludhiana (Punjab)	Sandy loam	5.5 (190)	5.4 (145)	5.1 (113)	5.2 (96)	40
Hissar (Haryana)	Sandy loam	5.7 (220)	5.2 (196)	4.7 (126)	-	43
Kota (Rajasthan)	Clay loam	5.4 (145)	5.3 (86)	5.1 (68)	-	53

Note: * - Drainage period in days after disappearance of ponded water
** - High water table condition
*** - With 3 day drainage vs.continuous submergence
Figures in parenthesis show irrigation water requirement (cm)
Source: Chaudhary, 1997 *vide*, Gupta *et.al.*, 2002

Table 20 presents data on wheat yields under zero-till technologies in farmer participatory trials in India. As evident the water savings realized range between 26 to over 35 percent for zero-tilled wheat as compared to conventionally tilled wheat. The wheat yields are also conspicuously higher in zero-tilled wheat ranging between 5780 to 6500 kg per ha as compared to 5190 kg per ha in the case of conventionally tilled wheat.

Table 20: Wheat Yield with Zero-Till Technologies in Farmer Participatory Trials

Item	Paired Planting*	Controlled Traffic**	ZT	FP-CT
Water Saving (%)	26.2	30.8	35.4	@
Yield (kg/ha)	6500	5800	5780	5190

Notes: * - Spacing between set rows (14 cm); and between paired sets (25 cm)
** - One row behind each tractor tyre not sown
@ - Compared with conventional tilled wheat planted a week later
Source: Gupta *et.al.*, 2002

Information about the effects of crop residues on zero-tilled wheat yields and savings in irrigation time in farmer participatory trials in Ghaziabad and Meerut districts in Uttar Pradesh State in India are presented in Table 21.

Table 21: Effects of Crop Residues on Yield of Zero-Till (ZT) planted Wheat and Saving in Irrigation Time in Farmer Participatory Trials in Ghaziabad and Meerut districts in Uttar Pradesh, India

Treatment	**No. of Plants/m^2**	**No. of Weeds/m^2**	**Total Irrigation Time (hrs)**	**Grain Yield kgs/ha**
Manually harvested Rice followed by ZT wheat	133	30	43.4 (31.8)	5650
Partial Residue burning followed by ZT wheat	132	30	46.2 (27.4)	5780
ZT planted wheat in combine harvested rice, mulched with shrub master	129	21	40.3 (36.7)	6000
Farmer Field Practices Convental Tilled	117	54	63.6	52.0

Note: Figures in parenthesis are percent saving in water in terms of irrigation time in relation to farmers practices

Source: Gupta *et.al.*, 2002

As evident, not only is there considerable savings in irrigation time for zero-tilled wheat as compared to conventionally tilled wheat but also wheat yields under zero-till situation are conspicuously higher (5650 to 6000 kg per ha) as compared to wheat yields under conventionally tilled situation (5200 kg per ha). Also the number of weeds was lower in zero-tilled wheat as compared to conventionally tilled wheat. A comparison of zero-tilled and conventionally tilled (farmers' practice) wheat yields after rice crop in Pakistan Punjab at different locations where the planting dates for the two methods differ indicates that on average wheat yields under zero-till i.e. 3677 kg per ha are conspicuously higher than under farmers' practice i.e. 2598 kg per ha (see Table 22).

Table 22: Wheat Yields after Rice in Zero-Tillage and Farmers' Practice Situations in Punjab, Pakistan at locations where the planting dates for the two methods differ

Locations	**Wheat Yield (kg/ha)**		**Days Difference**
	Zero-Tillage	**Farmers' Practice**	
Daska, Site 2	3143	3209	10
Daska, Site 2	3842	2735	13
Ahmed Nagar	4308	3526	20
Maujianwala	2689	2198	22
Mundir Sharif	4245	2660	33
Daska, Site 3	3838	3420	44
Average	3677	2598	24

Source: Aslam *et.al.*, 1993 *vide* Hobbs and Gupta, 2002

Table 23 also presents evidence on the effect of different tillage options such as direct seeded rice on beds, transplanted rice on beds, zero-tilled rice on flat, conventionally tilled rice fields, etc on rice grain yields. The table shows that in general other tillage options result in water savings and also report better rice grain yields as compared to conventionally tilled rice. Bed planting is another resource conserving technology that is being tried. Evidences from India suggest that farmers report 30 to 45 percent water savings during the wheat season and still higher during the rice growing season (Gupta et al, 2002, Hobbs and Gupta, 2002). It is also reported that farmers indicated that it is easier to irrigate with bed planting. When beds are kept submerged for the first few weeks and then irrigation supply frequency reduced later, the farmers were able to save around 30 percent water as well as overcome weed and iron chlorosis problems associated with bed planting systems (Gupta et al, 2002). However, another study notes that raised bed planting system gives rise to other problems such as the stability of bed slopes getting eroded due to rainfall and irrigation, transplanting on raised beds being disadvantageous as it requires higher man days than in flat lands, uneven beds leading to non-uniform plants along the bed, and weed problem since the bed is often under aerobic conditions, growth of weeds especially grass is promoted, etc (Cabangon et al, 2002).

Table 23: Effect of Tillage Options on Total Irrigation Time, Yield Attributes and Grain Yields of Rice

Tillage option	Total Experi-mental Area in ha	No. of plants m^2	Tillage/ Plant	Total Irrigation Time Hrs/ha	Produc-tion Tillers/ Plant	Spike Length cm	Grains/ Panicle	Grain Yield Mg per ha
Directed seeded Rice on beds+	14 (22)*	34	24	152.5 (39.0	15	22.6	165	50.2+
Transplanted Rice on beds	12 (20)*	35	24	146.0 (41.5)	19	23.4	173	56.2
Zero-Tilled Rice on Flat	12 (10)	56	16	205.0 (17.8)	13	21.9	163	56.9
Reduced Tilled Transplanted Rice on Flats	1.6 (7)	32	13	216.3 (13.3)	13	22.6	169	51.9
Conventional Tillage	14 (35)	27	16	249.5	12	21.5	163	52.9

Notes: 1. * Figures in parenthesis in Column 2 (i.e., Total experimental area) are the number of farmers participating in the trials.

2. Figures in parenthesis in Column 5 (i.e, Total irrigation time) are the percent saving in water in terms of irrigation time in relation to farmers practices.
3. + - Reduced yields due to severe iron chlorosis in initial crop growth stages and 8 missing beds per ha due to farmer experience

Source: Gupta *et.al.*, 2002

Another study analyzed the effect of different sowing methods i.e. laser leveling, zero tillage and bed planting as compared to normal planting on water savings, wheat yields and water productivity in Mona Project in Pakistan (Table 24). The table shows that the different sowing options leads to considerable water savings, higher wheat yields (4.1 to 4.8 t per ha as against 4 t per ha in the case of normal planting) and water productivity (i.e. 1.4 to 1.8 kg per cubic meter as against just 1.1 kg per cubic meter in the case of normal planting). The average water saved with laser leveling, zero tillage and bed planting over the traditional method was 715, 689 and 1329 cubic meter per ha valued at Rs 522, 503 and 907 per ha based on a water rate of Rs 900 per acre-foot for private tubewells for the year 1999-2000 (Hobbs and Gupta, 2002). Timely planting of rice also benefits the succeeding wheat crop by improving yields and water efficiency. Evidences from Eastern India, for instance, show that timely planting of rice improves wheat yields. Rice wheat system productivity in farmer participatory trials was nearly 12-13 tons per ha when rice was transplanted before June 28; this was reduced by more than 40 percent to 6-7 tons per ha when fields were planted after August 15 (Hobbs and Gupta, 2002).

Table 24: Wheat Yields and Irrigation Water Productivity under Alternative Resource Conserving Technologies in Mona Project, Pakistan

Item	**Laser Levelling**	**Zero Tillage**	**Bed Planting**	**Normal Planting**
Water applied (m^3/ha)	2849	2933	2281	3610
Yield (t/ha)	4764	4188	4134	3968
Water Productivity (kg/m^3)	1.67	1.43	1.81	1.10

Source: Gill *et.al.*, 2000 *vide* Hobbs and Gupta, 2002

While the above discussion is focused on ways of improving water use efficiency and productivity in irrigated agriculture, the problems of rainfed agriculture and less endowed or fragile regions cannot be overlooked. With prospects for bringing more area under irrigation being limited and the prohibitive costs of future irrigation investment, attention also needs to be focused on improving crop yields and water use efficiency and productivity in arid/semi arid and fragile regions. Managing water in agriculture should not exclusively focus on improving the productivity of the 2500 km^2 of water diverted to irrigation, but must also include improving the productivity of the 16,000 km^2 used in rainfed agriculture (IWMI, 2003). Rainfed agriculture contributes to about 60 percent of cereal production on 70 percent of the global cereal area (IWMI, 2003). For these areas research needs to be focused on evolving crop varieties and technologies that can tolerate droughts and moisture stress as well as the ability to thrive on low-quality water (IWMI, 2003). Reducing land degradation, supplemental irrigation combined with on-farm water harvesting practices such as mulching or bunding can reduce vulnerability to drought and helps farmers to get the most out of the scarce resources. Mitigating the effects of short-term drought is a key step in achieving higher yields and water productivity in rainfed areas (IWMI, 2003). In fact, deficit irrigation- a strategy that maximises the productivity of water by allowing crops to sustain some degree of water deficit and yield reduction is being advocated for water stressed areas (IWMI, 2003). Various forms of precision irrigation such as sprinkler, drip irrigation systems and dead-level basins can increase yields over good but ordinary irrigation systems by 20 to 70 percent, depending on the crop and other conditions, etc.(IWMI, 2003). Water reuse or recycling is also becoming an integral part of water management in water scarce areas. For instance, in the Indo-Gangetic plains many farmers employ shallow tubewells to recycle the water that percolates though the soil layer, thereby effectively capturing and using water before it flows out of the basin (IWMI, 2003).

Water Quality, Health and Sanitation

The problem of increasing water scarcity is further compounded by growing problems of water pollution caused by industrial, agricultural and urban wastes and insufficient investments in water infrastructure (Hoek, 2001). People and firms find it convenient to dump their wastes and pollutants into rivers, wetlands and other water courses at zero or low private costs, though albeit at high social costs. Apart from biological contamination of water, there is also the problem of contamination caused by naturally occurring chemicals in groundwater (Hoek, 2001). Deterioration in water quality and increasing water pollution not only reduces the availability of water fit for human consumption, aquatic life and livelihoods but also has adverse health effects and economic costs. For instance, it is estimated that about 3 to 5 million deaths per year take place in the world, especially among young children in developing countries due to diarrhea that is a water borne disease (Hoek, 2001). Water and sanitation related diseases are widespread and it is reported that nearly 250 million cases are reported every year, with more than 3 million deaths annually or about 10,000 deaths per day (Damme, 2001). In Bangladesh it is estimated that about 20 million people in the rural areas are exposed to high arsenic concentration in their drinking water that is toxic and carcinogenic (Hoek, 2001). In India it is estimated that 66 million people drink groundwater with too high a fluoride content which if taken in excess can cause dental and skeletal deformities and other health problems (Hoek, 2001). Tackling the problem of water pollution and improving water quality is, therefore, part of the larger objective of promoting sustainable use and management of water resources.

Access to safe drinking water and sanitation are recognized as basic human requirements (Gleick et al, 2002). Hence estimates of those who have or lack access to such facilities are taken as a measure of a country’s progress. Ensuring access to safe drinking water and sanitation are, therefore, part of every country’s development goals. About 1.1 billion people in the world are estimated to lack access to safe drinking water and about 2.4 billion people lack access to adequate sanitation (Damme, 2001). Table 25 sheds light on the proportion of people with access to safe drinking water and sanitation in urban and rural areas in selected Asian and non-Asian countries in the year 2000. In making cross country comparisons one should be aware of the limitations of such comparisons due to differences in concepts and definitions across countries as to what constitutes safe drinking water and sanitation, what is access, etc (Gleick et al, 2002). Gleick et al (2002) note that the definition of safe or improved water supply and safe or adequate sanitation facilities differ from country to country, and for a given country over time. As evident from the table, in both Asian and non-Asian countries the proportion of people with access to safe drinking water and sanitation is relatively higher in urban areas as compared to rural areas. This disparity is more conspicuous in developing countries as compared to developed countries. However one finds wide disparities in this regard between Asian countries. At one extreme one finds countries such as Afghanistan reporting only 19 percent of its urban population and 11 percent of its rural population having access to safe drinking water; and 25 percent of its urban population and just 8 percent of its rural population having access to sanitation. At the other extreme Korea DPR reports around 100 percent of their urban and rural population to have access to safe drinking water and sanitation. There are disparities even with regard to urban and rural access to safe drinking water and sanitation. For instance, both in China and India the urban and rural population are relatively better placed in respect of access to safe drinking water but the disparity is quite sharp in respect of access to sanitation. While 68 percent of the urban population in China has access to sanitation, for rural areas this proportion is only 24 percent. The corresponding figures for India are 73 and 14 percent respectively. Among non-Asian countries USA, Canada and Australia report cent percentage coverage of population with access to safe drinking water and sanitation in both urban and rural areas, while countries such as Congo, Congo DPR report very low proportion of rural population with access to safe drinking water and sanitation.

Improving water quality, access to safe drinking water and sanitation are part of the overall goal of promoting sustainable use and management of water resources, as noted earlier. Apart from using economic instruments, national governments and regulatory bodies have specified pollution standards to monitor and regulate air, water and other types of pollution. In the case of water pollution these standards prescribe the limits regarding biological contamination, fecal content, metal contamination, etc., such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, suspended solids (SS), number of colitis legions, lead and cadmium concentrations, etc. In general it appears that due to strict regulations and effective enforcement, pollution levels in water bodies in developed countries are less than in developing countries where often they are above the permissible levels. Conventional strategies for improving water quality have focused on treating drinking water separately from water used for other purposes (Heok, 2001). It is noted that many emerging water quality problems and potential solutions come from the interactions among uses, especially between domestic use and irrigation (Hoek, 2001). For instance, in many developing countries the rural people divert or use a part of the irrigation water for meeting their drinking water needs. Taking this into account an integrated approach is required to tackling water quality issues. In the context of mitigating water scarcity recycling of treated wastewater for use in agriculture and industries is recommended. In fact treated recycled wastewater is being used to meet the demand from industries as well grow vegetables and other crops in peri urban areas. However, there are health and food safety concerns regarding the use of recycled waste water especially for agriculture, and that over time they will lead to contamination of groundwater with nitrates, buildup of heavy metals and other chemical pollutants in the soil, create habitats for mosquitoes and other disease vectors, etc. (Hoek, 2001).

Water Institutions and Markets

Which institutional set up is ideal for promoting sustainable use and management of water resources is equally an important issue of concern. As long as water was considered as a free good and a plentiful resource, and water scarcities were not yet visible, issues such as efficiency and productivity as well as the suitability of public or state managed water institutions was also pushed to the background. However, with the emerging water crisis, heavy capital costs of augmenting water infrastructure and growing fiscal crisis of public or state run water institutions, focus is now shifted to finding appropriate institutional alternatives and mechanisms to promote sustainable use and management of water resources. Private or community managed water institutions or public-private partnerships are being increasingly looked upon as potential and viable alternatives to hitherto public or state controlled water institutions. It is felt that these alternatives will not only help promote sustainable and efficient use of scarce water resources, but also generate adequate resources for developing water infrastructure by reducing subsidies and also fostering cost sharing in developing and managing water resources. Water institutions which define the rules of water development, allocation and utilization thus need to be reoriented to reflect the realities of the changing supply-demand and quantity-quality balance (Saleth and Dinar, 2004). While discussing about institutional reforms there are also equity concerns that need to be addressed to since ensuring equity in use of available water resources is also essential for promoting sustainable use and management of water resources. Privatisation or community management of water resources may lead to cornering of access to and sharing of available water resources by the better off sections to the detriment of the economically and socially disadvantaged sections. In fact one study that reviewed the experience of water privatisation in Africa, Asia and Latin America notes that although privatisation was expected to improve efficiency and access to water it has failed to achieve the scale or benefits anticipated (Budds and McGranahan, 2003). This study is pessimistic about the role that privatisation can play in achieving the Millennium Development Goals of halving the number of people without access to water and sanitation by 2015. The study further notes that this is not because of some inherent contradiction between private profits and the public good, but because neither publicly nor privately operated utilities are well suited to serving majority of low income households with inadequate water and sanitation, and because many of the barriers to service provision in poor settlements can persist whether water and sanitation utilities are publicly or privately owned. Institutional reforms in the water sector also require an enabling legal framework and policies to realize the full potential of water sector reforms. Although privatisation and decentralisation are being increasingly emphasized in water sector reforms it is also acknowledged that the state or government will continue to have an important role to play as a regulator (Saleth and Dinar, 2004).

Development of formal and informal water markets and assignment of water user rights are being emphasized with a view to increase the incentive for efficient water use and making it possible to purchase water from areas where water is abundant (Easter et al, 1999). The ability to find another source of water, but at a higher marginal cost can also help promote community action for self-regulation and demand management (Easter et al, 1999). Informal water markets already exist in the irrigated areas of South Asia. One estimate suggests that 20 percent of the owners of the 14.2 million pumpsets in India are likely to be involved in water trading, implying that water markets are already providing water for about 6 million ha or 15 percent of the total area irrigated by groundwater (Saleth, 1998, vide Easter et al, 1999). In Pakistan a survey reported that 21 percent of well owners sold water (Easter et al, 1999). It is felt that informal markets can improve water use and incomes in irrigated areas where water rights are not well defined or recorded, and also be a better option if formal markets lead to disputes and high transactions costs (Easter at al, 1999). Informal markets would also work well in traditional irrigation systems where farmers manage the irrigation system and would be able to maintain a relatively modest level of transaction costs (Easter et al, 1999). Formal water markets exist in North and South America. Evidences from the USA, Canada and Mexico suggest that assignment of water use rights and water trading have been beneficial (Easter et al, 1999). However, a study of Water Users Associations (WUA) in Andhra Pradesh, India notes that although WUAs are promoted as non-political institutions, elite capture and political involvement dominate their functioning (Reddy and Reddy, 2005). More importantly, devolution of powers to WUAs has still not taken place, as most of the important functions like assessment, collection of water charges, sanctioning of works, etc remain in the hands of the irrigation department.

Conclusions

In the context of the growing demand for water and the emerging water crisis, attention is focused on finding appropriate strategies and mechanism to promote sustainable use and management of water resources. Since the prospects for supply augmentation are limited due to prohibitive cost of future irrigation investments and water infrastructure projects, focus is on demand management. Through proper pricing and institutional reforms in the water sector it is hoped that people and governments will be able to meet the increasing demand for water in various sectors. Reducing water wastages and improving water efficiency and productivity is an important goal. In this context efforts are underway to improve water productivity in agriculture, and the water so saved may be diverted for bringing more area under agriculture to boost food output, and meet the water needs of other sectors. With water being recognized as a basic human right ways are also being found to improve access to safe drinking water and sanitation. Institutional alternative such as private or community managed distribution of water, public-private partnerships and informal and formal markets are being explored with a view to improve the water sector so that it can meet the needs of an expanding population and economies. Recycling of wastewater, rediscovering traditional water harvesting practices are receiving considerable attention in recent years with a view to meet the increased demand for water.

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