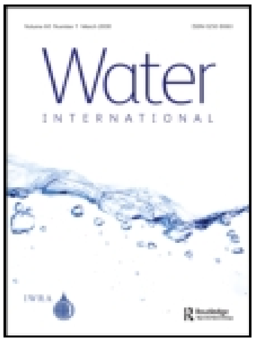

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The Indus and the Ganges: river basins under extreme pressure

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The basins of the Indus and Ganges rivers cover 2.20 million km^2 and are inhabited by more than a billion people. The region is under extreme pressures of population and poverty, unregulated utilization of the resources and low levels of productivity. The needs are: (1) development policies that are regionally differentiated to ensure resource sustainability and high productivity; (2) immediate development and implementation of policies for sound groundwater management and energy use; (3) improvement of the fragile food security and to broaden its base; and (4) policy changes to address land fragmentation and improved infrastructure. Meeting these needs will help to improve productivity, reduce rural poverty and improve overall human development.

Keywords: Indus-Ganges basins; water resources; water productivity; water poverty; water–energy nexus; potential interventions; water governance and policies

Introduction

Although the basins of the Indus and Ganges rivers are separate entities, they are contiguous. We shall therefore consider them together as the IGBs to enable comparisons and contrasts. The IGBs cover 2.2 million km^2 and have a population of about one billion, one of the world's densest. The IGBs' diverse agro-climatic, social and economic conditions in four countries, India, Pakistan, Nepal and Bangladesh, make them very complex. The IGBs have been cultivated and irrigated since 5000 B.C. Cultivation in the Indus Basin has intensified with massive resource development, especially recently. The Indus Basin irrigation system (IBIS) in Pakistan and the Bhakra irrigation system in India are the world's largest, generating surplus food that provides regional food security outside the IGBs (Amarasinghe *et al*. 2005). The IGBs were the seat of green revolution in Asia.

The performance of the large publicly funded irrigation infrastructure of the Indus has started to decline, however. Anarchic development of groundwater currently drives the rural economy (Mukherji *et al*. 2009a, Shah 2009) and meets the large domestic and industrial water needs. The groundwater is being exploited unsustainably, but is still expanding, creating large regional negative water balances. Falling water tables (Rodell *et al*. 2009)

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have also created an unviable nexus between water and energy (Scott and Sharma 2009). The Indus Basin is now practically closed with near zero environmental flows in most years.

The Ganges Basin has large supplies of both surface and groundwater but faces wide economic water scarcity (Molden *et al*. 2003), especially in Nepal, Bangladesh and eastern India. Land and water productivity for most crops and fisheries are low and the population dependent on agriculture (>85%) is very poor. There is prolific shallow groundwater, but it is poorly developed due to low rural electrification, high prices for diesel fuel, and tiny and scattered land holdings (Shah *et al*. 2009). The Ganges often floods during the monsoon season, and coastal Bangladesh is subject to cyclones, but there are dry spells and even droughts. Groundwater downstream is widely contaminated with arsenic (Chakraborti 2004).

There are complex transnational boundary issues in the IGBs. These, coupled with the weak water institutions, governance and policies at the local, national and regional level, seriously constrain implementation of basin-wide strategies and policies. Furthermore, climate change will alter the patterns of snow and glacier melt, and increase the frequency and intensity of floods and droughts. Its potential impact on agricultural yields, water resources, production systems and livelihoods in the IGBs calls for large-scale, multi-sectoral adaptation (Sharma 2009, Sharma and McCornick 2006, Hosterman *et al*. 2009). Fortunately, there are vast areas under rainfed mono-crops and more than 45% of the available water resources are un-appropriated, which presents opportunities to intensify farming systems and alleviate poverty.

This paper summarizes two years' research (2007–2009) supported by the Basin Focal Projects of the CGIAR Challenge Program on Water and Food. We shall review the challenges and opportunities in the IGBs in terms of hydrology, water resources and the variations in water and land productivity at the regional and local levels. We report on the prevalence of poverty at national, sub-national and household level, and its nexus with poverty for land and water and the opportunities to alleviate it. We further examine the state and effectiveness of existing water laws, policies and institutions in the region. Finally, we recommend interventions to improve productivity, reduce poverty and ensure sustainable use of resources.

Regional perspective

The IGBs (Figure 1) have a mosaic of interactions of poverty and prosperity, and problems and possibilities. Population growth reduced cultivable land per capita from 0.35 ha in 1880 to 0.19 ha in 1970. It halved to again to 0.10 ha in 2000. Agricultural water use increased rapidly, so access to water is central for livelihoods of the rural poor.

The Indus Basin covers an area of about 1.10 million km^2 distributed between Pakistan (63%), India (29%), and China and Afghanistan (8%) (Jain *et al.* 2009). The Indus has two main tributaries, Panjnad from the east formed by the five rivers Jhelum, Chenab, Ravi, Beas and Sutlej, and the Kabul River on the west. The Indus Water Treaty (1960) shares the Indus' waters between Pakistan and India.

The Ganges rises at Gangotri glacier in India. Its basin is about 1.09 million km^2, distributed between India (79%), Nepal (13%), Bangladesh (4%), and the rest in Tibet (China). The major tributary of Ganges is the Yamuna, which joins it at Allahabad. The Ganges then flows east joined by the further tributaries Ramganga, Gomti, Ghaghra, Gandak, Bagmati, Kosi, Sone and Damodar.

The upper reaches of both the Indus and the Ganges are in the high Karakoram and Himalayan mountains with many peaks over 7000 masl. The intensively cultivated area

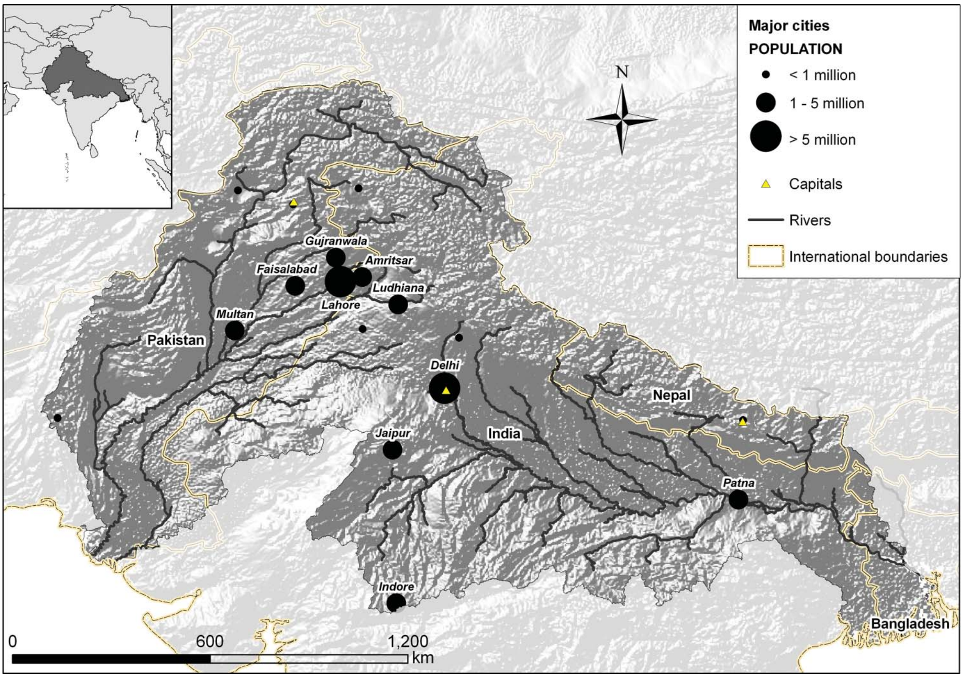

Figure 1. Map of the basins of the Indus and Ganges rivers.

Table 1. Socio-economic indicators of the countries of the Indus and Ganges basins.

Parameters	Bangladesh	India	Nepal	Pakistan
Access to improved water resources, %	74	86	90	91
Access to improved sanitation, %	39	33	35	59
Per capita electricity consumption, kWh	145	594	91	493
Population below national poverty line, %	49.8	28.6	30.9	32.6
Agriculture, % of gross domestic product (GDP)	20.1	18.3	38.2	21.6
Per capita GDP (USD)	406	640	252	632
IRWR (m^3/capita/yr)	688	1149	7539	325

Note: IRWR = Internally renewable water resources.
Source: Adapted from Babel and Wahid (2008).

of the contiguous Indus-Gangetic plains (IGP) is on fertile soils formed from alluvium. The Ganges delta lies downstream of Farakka barrage on the India–Bangladesh border.

The IGBs, with about one seventh of the world's population, are characterized by social and economic heterogeneity. In Nepal, 86% of the total population is rural, in Bangladesh 80%, in India 75%, and in Pakistan 68%. Poverty amongst the rural population is about 31% (2000) or more than 220 million, over half the total rural poor of South Asia. Table 1 shows indicators of the socio-economic conditions of the IGBs.

The net cropped area of the IGP is 1.14 million km^2, mainly to wheat, rice, cotton and sugarcane. The IGP produces 93% of the wheat and 58% of the rice produced in the IGBs' countries. Inland fisheries are important producers of food in the lower parts of the Ganges in India and Bangladesh. The economy and income levels are rising in the IGBs as a whole and in India in particular, which has implications for future water and food requirements (Amarasinghe *et al.* 2008). The eastern part of the Ganges Basin, where population densities are highest, was bypassed by the green revolution. It is still weak in rural infrastructure, market development, institutions, energy, credit for agricultural operations, location-specific technologies, surface-storage irrigation systems and development of groundwater resources. In contrast, the western region was the seat of green revolution and has high productivity, good irrigation (now dominated by groundwater), rural infrastructure and markets.

Water resources: use, abuse and non-use

Overall, the IGP has passed from common welfare irrigation systems in the ancient past, to imperialism and strict governance during the British colonialism, to the recent private-venture groundwater irrigation. There are important regional differences from the dynamic and progressive Indus Basin compared to the under-developed, introspective eastern part of the Ganges Basin. In the west, the overarching issue is sustainable management of water and land resources; in the east, it is access to resources and institutions, livelihoods, poverty and food security.

Annual flow in the Indus is 120–230 km^3 (1957–97) with only about 10% net discharge, with glacier melt providing stream flow in the upper basin. Average annual flow in the Ganges varies from 5.9 km^3 upstream at Tons River to 459 km^3 at Farakka barrage. Northern tributaries, especially in Nepal, contribute substantially (Jain *et al*. 2007). The mean annual input from rainfall to the Ganges Basin is 1170 km^3. Net discharge of the Ganges is about 429 km^3 (37% of the input). It is the largest water use, followed by rainfed agriculture. Groundwater is not uniformly available across the IGP; recharge in some parts of the Indus is < 2 mm/yr, while in Nepal and Bangladesh groundwater recharge is medium to high. In addition to the dynamic groundwater resource, which is commonly pumped, there is a massive static (unused) groundwater resource of about 9170 km^3, 85% of which is in the Ganges Basin.

Water use in the IGBs is dominated by agriculture, which uses 91% followed by 7.8% for domestic use (Eastham *et al*. 2010). Irrigated agriculture uses about 286 km^3, 23% of the total water use. IBIS in Pakistan is the world's largest irrigation network, with an area of 17 Mha and an intake of almost 75% of the water in the Indus River. A large proportion of the groundwater in the Indus Basin is pumped by irrigators; in contrast, they pump only 54% of the groundwater available in the Ganges Basin. Demographic pressures and industrial development influence the distribution of water between sectors (Table 2). Amarasinghe *et al*. (2007) forecast demand for domestic and industrial water to increase in the near future.

Floods and droughts kill people and seriously damage crops, livestock and infrastructure. With climate change they are predicted to increase in frequency and severity

Table 2. Water demands in the Indus (down to Kotri), and the Ganges (down to Farakka).

	Demands			
Basin	Irrigation	Domestic	Industries	Total
	km^3/yr (%)	*km^3/yr (%)*	*km^3/yr (%)*	*km^3/yr*
Ganges	93.9 (82.1)	10.7 (9.4)	9.8 (8.6)	114.4
Indus	168.7 (95.5)	4.4 (2.5)	3.4 (2.0)	176.5

Source: Adapted from Amarasinghe *et al*. (2007), Habib (2004), and the Bhakra Beas Management Board (http://bbmb.gov.in/english).

(Aggarwal *et al*. 2004). The Indus Basin ranked in the top ten of the world's most vulnerable with inflows predicted to fall by 27% by 2050 (IPCC 2001). Glacier melt is the major water source for the IGBs and hence of water for irrigation so that reduced glacier melt will therefore impact food production in the IGP. There was an overall deglaciation of 21% since 1962 in 466 glaciers in the Chenab, Parbati and Bapsa basins. The Gangotri glacier retreated an alarming 100 m between 1994 and 1998 (Tangri 2000).

The combination of glacial retreat, decreasing ice mass, early snowmelt and increased winter stream flow suggest that climate change is already affecting the Himalayan cryosphere (Kulkarni *et al*. 2007). Reduced surface runoff will reduce groundwater recharge and affect the groundwater dynamics in the region, which will be critical in the western region, where most irrigation is from groundwater. Strength-weakness-opportunity-threat (SWOT) analysis showed an overall reduction in runoff in both rivers under all greenhouse gas emission scenarios (Gosain and Rao 2007).

Floods are common in the Ganges Basin, with the Ganges itself and its tributaries Yamuna, Sone, Ghagra, Gandak, Koshi and Mahananda all flooding annually. Bangladesh is flooded almost every year by the Ganges, Brahmaputra and Meghna rivers. These are transnational rivers, so it is difficult for the individual government to implement appropriate and timely measures for forecasting and moderating floods.

Water control and land use

We did Soil Water Assessment Tool (SWAT) modelling of three sub-basins, Gorai (Bangladesh), Upper Ganga (India) and Koshi (Nepal). Completion of the upstream Farakka barrage in 1974 changed the inflow to Gorai, which is critical for growing rice in the dry season. The 1965–75 inflows in February and March averaged 17 MCM, but only averaged 2 MCM in 1990–9. The annual downstream runoff from Gorai averaged 188 mm in 1990–9, 26% less than in 1965–75. Additionally, abstraction between Farakka and Gorai further lessens inflow. Farmers in Gorai had to abandon rice for less demanding crops and develop groundwater to make up the shortfall.

Dams, barrages, and canals regulate flow in the upper Ganges River (Figure 2). Rainfall and evapotranspiration are less and water yield is higher in the upper catchments, especially where structures control runoff. Evapotranspiration was highest for the forested areas followed by irrigated areas.

The southern part of the Koshi sub-basin is wetter than the trans-Himalayan northern part. Evapotranspiration is higher in the south than in the north but runoff exceeds evapotranspiration in the south because of higher rainfall. Optimal resource planning at the regional level requires detailed modelling of the existing and future scenarios at the sub-basin level.

Water productivity: assessment and improvement

Crop water productivity (WP) indicates food security at a basin scale and can guide policies to adapt to climate change. We mapped WP in the whole IGBs by integrating crop census data with remote sensing and GIS. First we mapped dominant crops using census data and existing maps of land use and land cover. We calculated yields from national statistics and interpolated them to pixel level (250 m $\times$ 250 m) using the normalized difference vegetation index (NDVI) satellite data. We mapped crop evapotranspiration (ET_a) using a simplified surface energy balance (SEBAL) model based on satellite data of land surface temperature and data from 56 weather stations. We mapped WP for rice and wheat

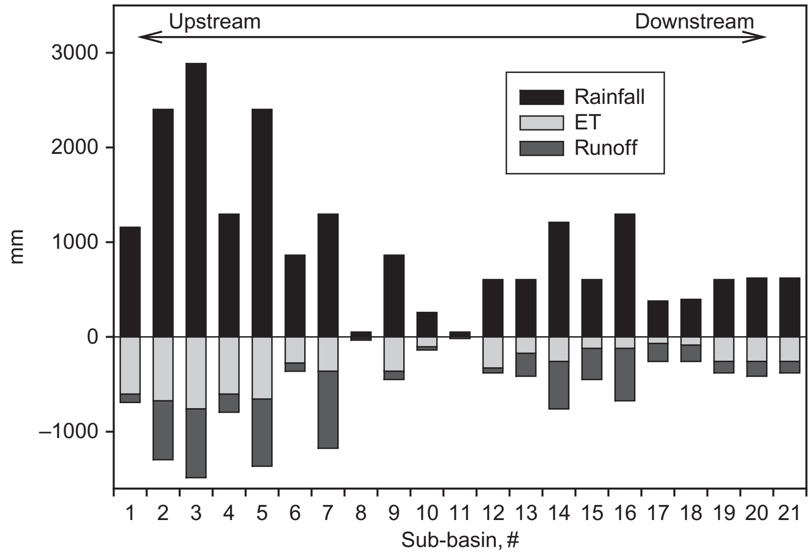

Figure 2. Impact of water control and land uses on the water balance components of rainfall, evapotranspiration (ET), and runoff from sub-basins within the catchment of the upper Ganga (Ganges) River in Uttar Pradesh.

and total agricultural yield by dividing crop yield by ET_a for each pixel (Ahmad *et al*. 2009, Cai and Sharma 2010).

The WP map displays the spatial variation in great detail. We can identify well-performing bright spots and low performing hot spots regardless of administrative boundaries. Linking them to rainfall distribution, topography, groundwater level and other spatial information can indicate causal relationships, which is useful to provide information for improved intervention planning.

The IGBs are intensively cropped with more than 50% of the total area under cultivation. The dominant system is a rice–wheat rotation, mixed with cotton, sugarcane, pulses, oilseeds, millet and jute. Rice (32.3% of the total area) and wheat (27.5%) occupy more than half the area under cultivation. Both crops are irrigated, but need better water management. We look at the WP of the rice–wheat system in more detail below.

Physical water productivity of rice

The average rice yields for the Pakistan, India, Nepal and Bangladesh parts of the IGBs (Figure 3) are 2.60, 2.53, 3.54 and 2.75 t/ha, respectively, but differ widely across the region.

The Indian Punjab state, with some adjacent areas of Haryana and Rajasthan states (dark patch in Figure 3[c]) has an average yield of 6.18 t/ha, significantly higher than most other parts of the Indus Basin. The rice yields of the Indian states of Madhya Pradesh (1.18 t/ha), Rajasthan (1.49 t/ha), and Bihar (2.04 t/ha) in the Ganges Basin are low, which accounts for India's low average yield. The map of rice yield at pixel resolution shows yield variations at the local scale. For example, about 1% of the area (adjacent to the foothills) around the high-yielding Punjab yields less than 3 t/ha. In contrast, although the mean yield of Bihar is only 2.04 t/ha, there is a 37 km circular area southwest of the Bhojpur district that yields 4 t/ha. This area in Bihar is well served by the conjunctive use of the

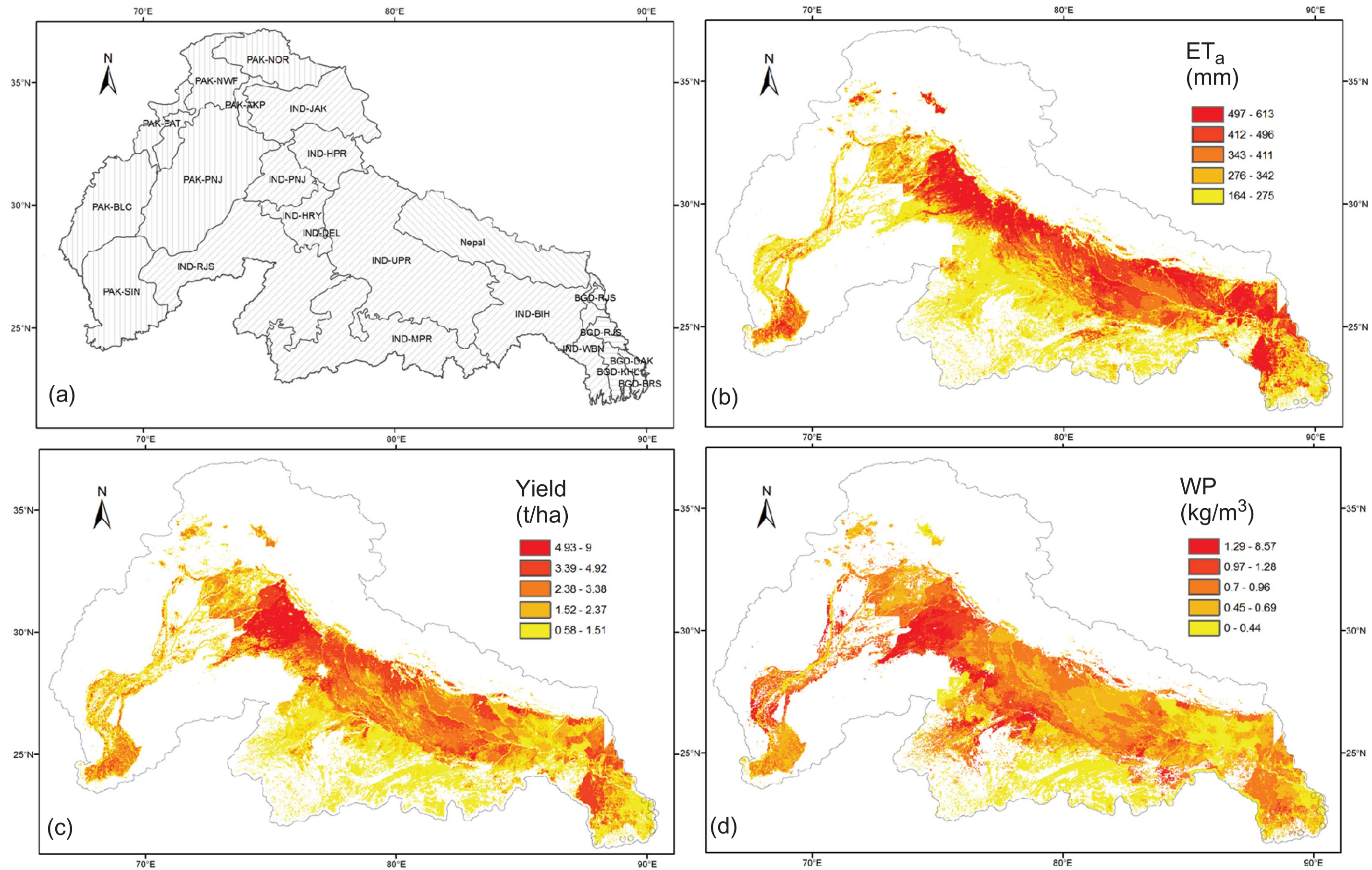

Figure 3. Rice in the IGBs for the year 2005: (a) administrative boundaries; (b) ET_a; (c) yield; and (d) water productivity.

Sone canal system and tubewells, as well as widespread adoption of improved agronomic practices.

ET_a is a measure of how much water a particular ground cover uses. A crop's potential ET_a is its evapotranspiration without water or nutrient limitation. ET_a data indicate the water-use efficiency of irrigation, and low ET_a values indicate stressed rice or mixed cropping.

The ET_a of paddy rice in the IGBs for the growing season 10 June–15 October 2005 averaged 416 mm (range 167–608 mm, standard deviation (SD) 104.6 mm), which is significantly less than the rice potential evapotranspiration (ETp, 610 mm). There is significant variation of ET_a across the region (Figure 3[b]). The adjoining areas of the Indus and Ganges basins in Punjab, Haryana and west Uttar Pradesh, covering 8% of the total rice area, have ET_as averaging 551 mm. ET_a is also high in north West Bengal (528 mm), and in a belt from the Khulna division of Bangladesh to the Indian states of West Bengal, northern Bihar, central Uttar Pradesh, Haryana and Punjab (Figure 3[b]). ET_a is low in Madhya Pradesh and Rajasthan states in India, which are distant from the Ganges River, and in south Punjab and north Sind provinces in Pakistan, where there is more mixed cropping. Overall, ET_a follows yield, although in Bihar ET_a is high but yields are low, indicating low irrigation efficiency.

Average WP of rice in the IGBs is 0.74 kg/m^3 (0.18–1.8 kg/m^3, SD 0.329), with the pattern of WP generally following that of yield. WP of the Indian Punjab and adjoining areas that cover 6% of the IGBs' rice area averages 1.32 kg/m^3. About 23% of the IGBs' rice areas, mainly in Madhya Pradesh and Bihar in India and the Dhaka division of Bangladesh, all in the Ganges Basin, have WP less than 0.5 kg/m^3. These areas are not adequately served by surface or groundwater resources and could benefit from improved access to irrigation.

Physical water productivity of wheat

Wheat yield in the IGBs averaged 2.65 t/ha (SD 1.0 t/ha.). Yield distribution is similar to rice (Figure 4[a]). Bright spots are in the Indian states of Punjab and Haryana where yields average 4.4 t/ha and somewhat lower in the upstream Indus in Pakistan, in west Uttar Pradesh, and northeast Rajasthan in India. Hot spots, with yield levels of only 0.70–1.58 t/ha, are in the Ganges Basin in Bihar and West Bengal states in India and in Bangladesh. The yield differences in irrigated wheat are likely caused by soil, fertilizer and crop variety rather than water.

Wheat is grown in the cooler season, so that evapotranspiration 24 November 2005–14 April 2006 averaged 299 mm (SD 61 mm). Wheat ET_a follows the same pattern as yields (Figure 4[b]) with the bright spots in the areas where yields were high. Elsewhere, ET_a is relatively low and uniform. WP of wheat averages 0.94 kg/m^3 (SD 0.66 kg/m^3). Despite low yields in Rajasthan and Madhya Pradesh, WP is higher because of the low ET_a and short growing season. These states grow low-yielding traditional varieties with high cooking quality, which fetch premium prices. The areas with the highest yields had high WP, but not the highest. Bihar in India has large areas of low WP, indicating scope for improvement.

Annual economic water productivity of rice–wheat cropping system

WP of rice in 2005 at local market prices was US$0.121/m^3, and for wheat was US$0.148/m^3, reflecting the differing physical WPs of the crops and the higher price

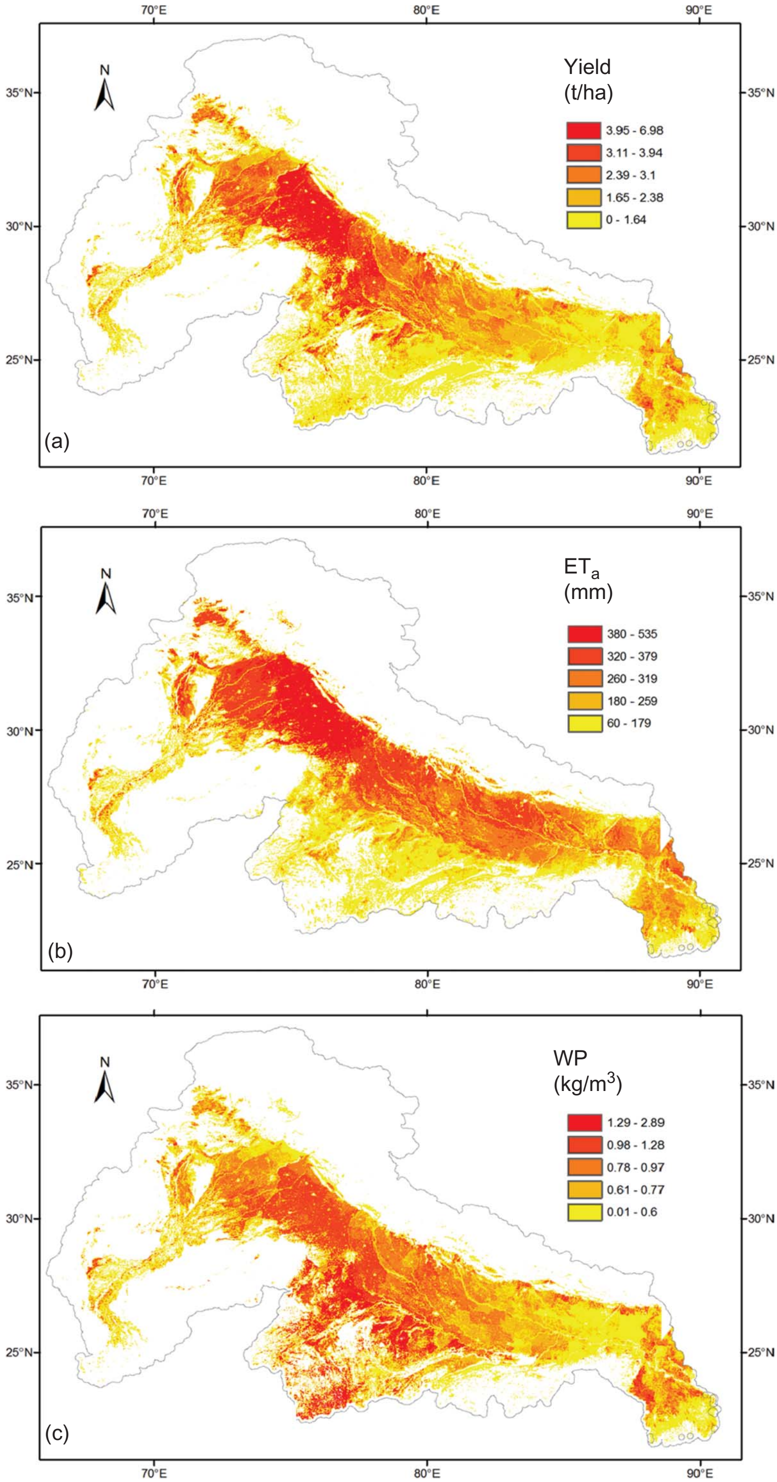

Figure 4. Wheat in the IGBs for the year 2005/6: (a) yield; (b) ET_a; and (c) water productivity.

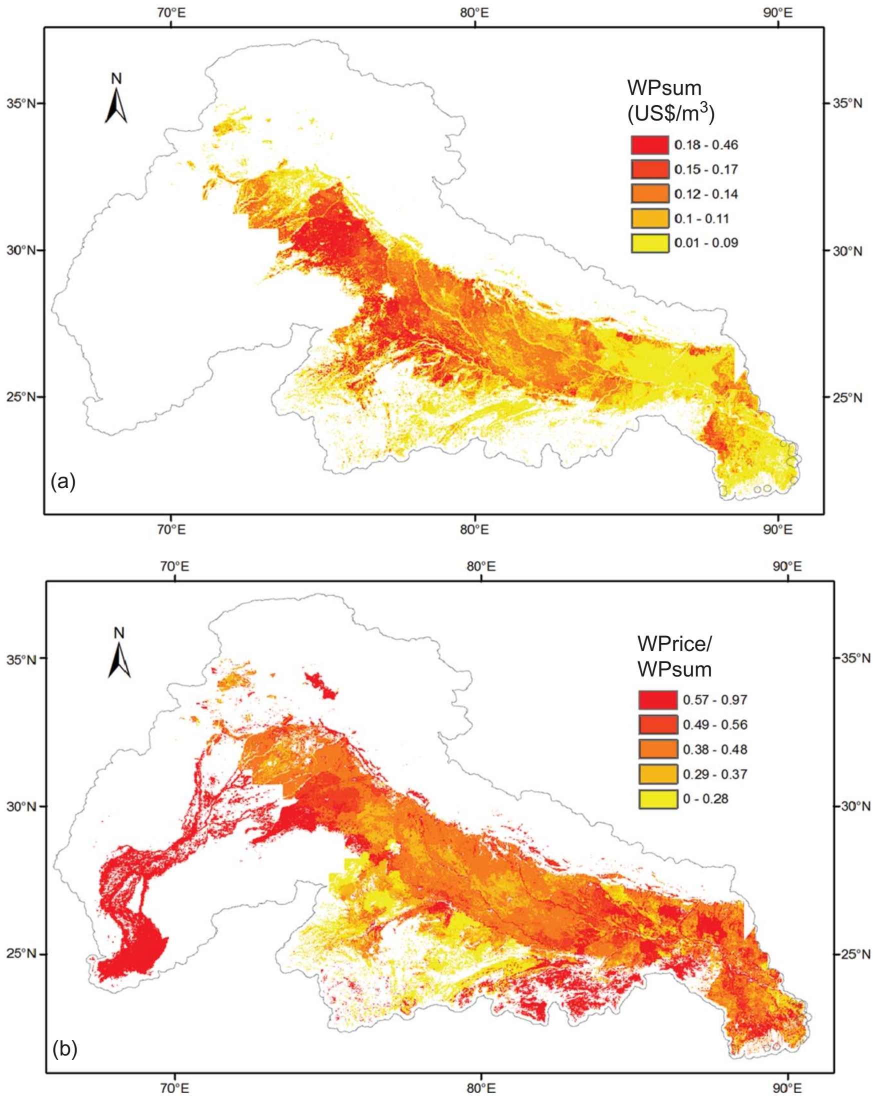

Figure 5. The rice–wheat rotation in the IGBs for the year 2005/6: (a) economic WP (WPsum); and (b) the contribution of rice (WPrice/WPsum).

for rice. WP for the rice–wheat rotation is US$0.131/m^3 (Figure 5). Economic WP for the rice–wheat system is different from either crop alone. The border areas of Rajasthan, Madhya Pradesh and Uttar Pradesh together with the Indian Punjab perform best with the combined system. Rice contributed 50.7% to the combined system despite lower WP because the cropped area is larger.

Factors affecting variation in water productivity

Rainfall in the IGBs is much higher during rice growing season (*kharif*) than that of wheat (*rabi*). Moreover, rainfall in the Indus Basin is much lower than in the Ganges Basin during *kharif* but is reversed in *rabi*. Temperatures of the land surface are similar across basins and seasons. Temperatures are hottest in the deserts of the downstream Indus Basin, and coldest in the northern mountains. Topographically the IGP is flat although the southern Ganges Basin is higher.

Potential evapotranspiration (ET_p) is lower in the Ganges Basin than the Indus, reflecting the differences in rainfall distribution. Crop stress (ET_a/ET_p, the lower the ratio the greater the stress) is widespread in the Indus Basin and in the south Ganges Basin. As a closed basin, the Indus faces severe water scarcity. In contrast, the well-performing Indian Punjab shows little water stress in spite of the deep groundwater table and low rainfall. High water availability in the eastern Ganges does not give higher yields or WP.

Rainfed crops are more vulnerable, so that rainfed paddy may have more standing water at times but can still suffer from water stress at critical growth stages, such as grain filling, which can reduce grain yield. Rice is also vulnerable to excess water particularly soon after establishment. Adequate irrigation and drainage systems and appropriate management can maximize utilization of rainfall and river flows to achieve high yield and WP. Other land and crop interventions, such as laser land levelling, furrow-irrigated raised beds (FIRBS), control of insects and diseases, optimum fertilizer and suitable varieties, are part of the agronomic package.

Yields, ET_a and WP of wheat are more consistent across the IGBs. High ET_a, yields and WP occur together. Irrigation is the main control of ET_a in the dry *rabi* season, so that wheat yields are more related to irrigation volume. The high wheat yields in the Haryana, and the Indian and Pakistani Punjab come from the extensive irrigation from groundwater, which is over-exploited and unsustainable.

Yield and WP vary consistently where water availability is the major constraining factor, such as the downstream Indus Basin and downstream areas in the southern Ganges Basin. Elsewhere in the Ganges, yields and WP are not constrained by water availability, or climate, but the irrigation infrastructure, access to irrigation water and crop management.

The bright spot for both rice and wheat in the Indian Punjab and adjacent areas, with only 5% of the IGBs' area cropped to rice and wheat, has the high WP of US\$0.190/m^3. If the basin average of US\$0.131/m^3 could be increased to the same as in bright spots, the basin could use 31% less water for the same production, or increase production by 31% with the same amount of water. There are many constraints to achieving this theoretical optimum, but there are clearly possibilities to increase WP, which would be important for regional food security.

Potential interventions for improving water productivity

Cropping patterns and sources of irrigation water have changed greatly in the IGBs. The area under paddy has grown exponentially, while water tables have dropped due to pumping of groundwater in the Indian and Pakistani Punjab, Haryana and western Uttar Pradesh. Intensive production of irrigated rice and wheat with limited water resources is hydrologically unsustainable. In contrast, the abundant water available in the eastern Ganges Basin is underdeveloped and underutilized, so that land and water productivity are low. A variety of physical, crop-related, and policy interventions have been tried in the IGBs but with varying degrees of success. We analyse some of the successful ones below.

Potential interventions for selected crops of the Indus and Ganges basin

We used the analytic hierarchy process (AHP) (Saaty 1980) to rank potential interventions. We selected eight crops from the major cropping systems in the IGBs (Biswas *et al*. 2006),

Table 3. Priority ranking of three most important interventions for productivity improvement of the selected crop in the Indus and Ganges basins.

Crops	Interventions	Rank
Rice	Crop diversification with legume-chickpea with furrow-irrigated raised bed planting technique in sequence and intercropping.	1
	Transplanted rice on raised bed (bed-planted system).	2
	Use of suitable cultivars for direct seeded rice.	3
Wheat	Use of 100% recommended dose of nitrogen and phosphorus + FYM/Gypsum/ under no till	1
	Timeliness in sowing operation: sowing by third week of November	2
	Proper irrigation scheduling and maintenance of moisture regime	3
Maize	Use of hybrid variety seeds	1
	Cultivation on permanent raised-bed planting system	2
	Proper irrigation scheduling and maintenance of moisture regime	3
Sugarcane	Proper irrigation scheduling and alternate or skip furrow method	1
	Timeliness in planting operation	2
	Furrow planting	3
Pulses	Crop diversification: short-duration mung bean as summer crop	1
	Multi-crop zero-till-drill *cum* bed planting	2
	Crop diversification: chickpea and lentil in rotation with wheat	3
Oilseeds	Selection of suitable cultivars and hybrid seeds	1
	Laser land levelling	2
	Crop diversification: intercropping with Indian mustard and sugarcane	3
Potato	Planting with quality seed	1
	Proper irrigation scheduling and moisture regime	2
	Basal application of farmyard manure	3
Tomato	Integrated pest management	1
	Use of quality seed and seedlings	2
	Integrated nutrient management	3

and identified multiple, crop-specific interventions to improve WP. We sorted the interventions for each crop based on values in the literature of their impact on water productivity. We made up questionnaires that included the interventions for each crop and sought the expert opinions of 216 experts/stakeholders covering the whole IGBs, including 88 scientists, 18 government officials, 106 farmers and four non-governmental organizations (NGOs).

We analysed the responses and selected the three top-ranked interventions for each of the selected crops (Table 3). Each of these interventions has a large potential to improve land and water productivity of the specific crops. The benefits of each of the interventions need to be explained to farmers, and market and infrastructure linkages need to be established for adequate and timely supply of the required inputs.

The study showed that the potential interventions for improving WP are crop-specific. Proper irrigation scheduling is important for sugarcane, potato, maize and wheat, while high-quality hybrid seeds of suitable cultivars were important for maize, potato and oilseeds. Suitable cultivars and crop diversification with legumes were important for rice and pulses.

Farmers identified the amount and timing of irrigation scheduling as important. Specifically, farmers need to know the critical growth stages for each crop in the different regions so as to facilitate proper irrigation scheduling. Similarly, farmers need up-to-date knowledge on crop diversification, hybrid seeds, quality seeds, suitable cultivars and integrated nutrient management to enable them to improve WP.

Adoption of resource conservation technologies (RCTs)

Improved physical WP in agriculture would reduce the need for additional water and land, and is a critical response to water scarcity. RCTs can save water and increase productivity, especially in the arid and semi-arid parts in the northwest Indus Basin where water scarcity limits crop yields. RCTs emphasize minimum till and mulch with crop residues and have been adopted in about 2 M ha in the IGBs. Technologies promoted in the IGP include reduced/zero tillage, laser land levelling, raised bed planting, and direct seeding of rice, either alone or combined. Zero till (ZT) in wheat and laser land levelling is widely adopted in the IGBs.

ZT gives 12% more utilization of water (Sikka *et al*. 2003) and reduces the number of irrigations per season. In the rice–wheat system at Rechna Doab in the Indus Basin (Pakistan), farmers used 24% less water with ZT, and saved 52% on fuel implying much less groundwater pumping. The influence of different RCTs in the field on WP is summarized in Table 4. However, factors involved in scaling up to sub-basin or basin scale are not fully understood (Ahmad *et al.* 2007). Higher WP with RCTs may come from yield gains, or saved water, or both. Water savings reduce flows to saline groundwater sinks, as in Rechna Doab where groundwater is more saline, which could have broader implications for water quality.

Water saving through watercourse improvements: case of Indus Basin irrigation system

High conveyance losses contributed to low WP in the IBIS. The national program for the improvement of watercourses (NPIW) in Pakistan expected to improve a total of 28,000 watercourses in IBIS in the Punjab at a cost in 2004 of US$1.1 billion. We found that improved watercourses improved the efficiency of water delivery (Table 5). Before improvement, the average time taken to irrigate one hectare of land, irrespective of farm size, at the head, middle and tail sections of a watercourse was 4.5 h, 6.75 h, and 5.25 h,

Table 4. Water productivity improvements in rice–wheat systems of the IGBs by different resource conservation technologies.

Technology/ Location	Irrigation water productivity	Increase (from conventional)
	kg/m³	%
Zero tillage		
Haryana[a]		
Canal	3.69	33.2
Groundwater	2.23	21.5
Mona Project, Pakistan[b]	1.43	30.0
Sheikhupura district, Pakistan[c]	3.00	19.5
Bed planting		
Sheikhupura district, Pakistan[c]	2.98	18.7
Mona Project, Pakistan[b]	1.81	64.5
Laser land levelling		
Modipuram, Uttar Pradesh, India[d]		
Laser land levelling (wheat)	1.31	59.8
Laser levelling and raised bed (wheat)	1.90	37.7
Laser levelling (rice)	0.91	65.5
Mona project, Pakistan[b]	1.67	51.8

Sources: [a] Erenstein *et al*. (2007), [b] Hobbs and Gupta (2007), [c] Jehangir *et al*. (2007), [d] Jat *et al*. (2005).

Table 5. Improvement in delivery efficiency (%) as a result of watercourse improvement in the Indus Basin irrigation system.

	Delivery efficiency of main water course[1]				Overall delivery efficiency[2]			
Project	Head	Middle	Tail	Average	Head	Middle	Tail	Average
Pre-improvement	76	71	63	70	66	63	54	61
Post-improvement	82	81	74	80	79	73	64	72

[1] Efficiency of the section between watercourse outlet *(mogha)* and farm outlet *(nakka)*
[2] Efficiency of the section between watercourse outlet *(mogha)* and field outlet *(nakka)*

respectively. After improvement, irrigation time was reduced about 22%, 40% and 19%, and cropping intensities increased from 115%, 121% and 115% to 138%, 151% and 132%, respectively.

Policy intervention to save water: Punjab (Indian) Preservation of Subsoil Water Act 2009

The Indus Basin depends heavily on groundwater, which is over-exploited. Current energy subsidies and grain price support encourage farmers to grow flooded rice, even in areas where groundwater is overused. In the Indian Punjab, the *Punjab Preservation of Subsoil Water Act 2009* prohibits transplanting rice before 10 June to avoid water losses from flooded fields in the hot weather that precedes the monsoon. Synchronizing the rice crop with the monsoon decreases the water required by flooded rice by 260–300 mm and saves about 2.10 km^3 over the rice-growing area of the Indian Punjab (Figure 6). The water table will still fall but at 60–65% of its current rate (Sharma and Ambili 2010), and less water pumped will save up to 175 million kW h electricity. Growing short-duration varieties like PR115 will save even more water (Figure 6).

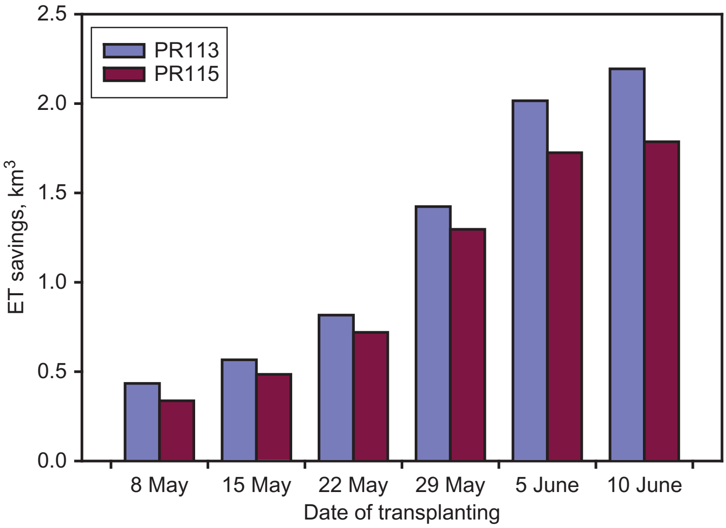

Figure 6. Savings in water by delayed transplanting over the total rice area in Punjab for two rice varieties (PR113 and PR115).

Multiple water-use schemes in hill areas

Short, sloping terraces in the hills of the upper Indus and Ganges Basins are unsuitable for surface and groundwater irrigation. A multiple water-use scheme (MUS) in the Nepalese hills provides a solution by supplying household water and water for homestead gardens (Mikhail and Yoder 2009). Water is piped from upstream springs to a 3000 L ferro-cement water tank (Thai jar), which provides household water (45 L/person/day), the first priority. Overflow is collected in a larger 10 m^3 underground tank, which supplies irrigation water to household vegetable gardens (400–600 L/household) where it is applied by a low-cost drip system (Sharma *et al*. 2010). The average cost is US$100/household in cash and kind. Sale of surplus vegetables (about 90% of production) meets the cost in the first year (Sharma *et al*. 2010) and provides continuing cash income.

MUSs cover 10 to 40, occasionally 80, households depending on the community and the availability of water. They provide potable water to households, reduce the incidence of water-borne diseases, and eliminate the drudgery for women in fetching water. Where conditions are suitable, MUSs are expanding rapidly, supported by partnerships between government agencies, local institutions, NGOs and private parties.

Agrarian change and water institutions

Although the water sector has successfully developed technical solutions to meet the growing water needs of the economy and society in the past, it is getting harder. All sectors demand more water, but development of additional water resources is difficult and expensive, and already there are conflicts over sharing the water that is available. Hence governance plays a critical role in the water sector.

The water sector of the IGBs has many informal institutional arrangements, which co-exist with large formal institutions. We know or understand little about how they operate at the regional level or over different tiers of regional management. In particular, we do not know their relative strengths, weaknesses and efficacy in response to variations in resource availability, economics and politics. In short, there is no comprehensive analysis of water governance in the IGBs. We discuss below some issues of water governance and water laws in the IGBs.

Is irrigation water really free in the Indus-Ganges Region?

It is widely believed that pricing water according to its actual cost will prevent waste, misallocation and scarcity. But in the IGBs it does not appear to be that simple. When the cost of water rises above a low threshold, many small farmers do improve the efficiency of water use by lining channels or using pipes, and by switching to water-saving crops. When the cost of water rises beyond some upper threshold, however, farmers are forced to make drastic cuts in their use of irrigation water, stop growing irrigated crops, or even quit farming. Increasing the price of water does increase the efficiency of water use but threatens the livelihoods and food security of millions of agrarian poor (Shah *et al*. 2009).

Water in public irrigation (canal and tanks) on 20–22 Mha is cheap (US$0.0025–0.02/$m^3$) (Figure 7). The dearest water (US$0.15–0.25/$m^3$) is from hired diesel-powered generators to power submersible electric pumps on deep tubewells, used only in case of emergency. The dearest water costs up to 100 times the cheapest, but about 80% of land in the IGBs is irrigated at non-trivial cost. In sub-economy II (Figure 7), water from electrified tubewells, electricity is the main cost (US$0.01–0.0175/kW h) and volumetric in Punjab,

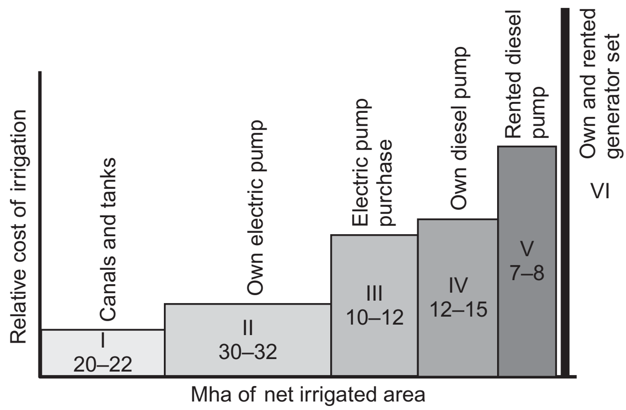

Figure 7. Irrigation sub-economies of South Asia.
Source: Shah *et al*. (2009).

and Sind in Pakistan, in Nepal and in Bangladesh. In India, electric tubewell owners pay a flat tariff (except in Punjab where electricity for pumping is free), but there is stringent rationing of the increasingly unreliable power supply. Farmers in sub-economies I, II and III are increasingly using diesel-powered pumps to cope with the unreliability of surface irrigation (I) and electricity supplies (II and III).

The diesel-fuel price squeeze

Indian Punjab and Haryana have many electric tubewells, but the rest of the IGBs depend on diesel pumps for water because in Bangladesh and Pakistan farm electricity is metered and expensive, or is not available as in Bihar and Nepal Terai. The price of diesel fuel increased by 670% between 1990 and 2006, while the farm-gate price of rice rose only about 60%. The squeeze on small-scale irrigation is therefore approaching crisis in all IGBs' countries but particularly in eastern India and Nepal Terai (Table 6).

Case studies of 19 villages of the Indian Ganges Basin and the Pakistan Indus Basin showed two responses: increased efficiency or distress. Farmers increase efficiency by improving distribution, by lining field channels or using pipes, by just-in-time irrigation, by reducing irrigation frequency, and by switching to crops that need less water. In eastern India, farmers also commonly switch from Indian to cheaper Chinese diesel pumps. Distress responses include quitting farming, mostly by marginal farmers and sharecroppers dependent on expensive purchased water. Other smallholders switch to

Table 6. Farm-gate price relative to the price of diesel fuel in IGBs countries.

	Diesel price: February 2007	Farm-gate rice price: February 2007	Rice needed to buy one litre of diesel
	/litre	*/kg*	*kg*
India (Indian Rs.)	34.0(US$0.85)	6.4	5.7
Pakistan (Pak. Rs.)	37.8(US$0.64)	11.8	3.2
Bangladesh (Taka)	35.0(US$0.50)	9.0	3.9
Nepal terai (Nepal Rs.)	57.0(US$0.84)	10.0	5.7

Source: Data collected from case studies undertaken for this research.

high-risk, high-value crops on a small plot leaving the rest of the farm fallow or under rainfed crop.

Energy and irrigation in the IGBs

Over the last 50 years, groundwater has become the main source of water for irrigation in the IGBs, with the green revolution often titled the tubewell revolution (Repetto 1994). But while the use of groundwater boomed, it did so at the cost of the energy economy. In the late 1970s all state electricity boards (SEBs) in India changed from metered electricity to a subsidized flat-rate tariff. The cost of supply soon exceeded revenue earned and most SEBs made huge losses.

Since the marginal cost of pumping groundwater was near zero, there was over-pumping and in places groundwater markets developed. In arid and semi-arid regions with hard-rock aquifers and low recharge, water tables fell sharply, putting the livelihoods of millions of poor farmers, who depended on groundwater irrigation, in jeopardy (Moench 1996). In contrast, in areas with abundant rainfall and alluvial aquifers with adequate recharge, such as Bihar and West Bengal (Mukherji 2007, 2009b) the groundwater system is more robust and was not over-pumped, due in part to inadequate electricity infrastructure.

There are therefore two energy-irrigation stories in the IGBs. The first is the vicious cycle of low, flat electricity tariffs, leading to over-pumping of groundwater and bankrupt SEBs, which is difficult to break due to the political power of the farmers with entrenched interests. This is true for Punjab, Haryana and western UP in India. The second is less often told. In water-abundant eastern India, Nepal Terai and Bangladesh, farmers mostly use diesel pumps, which have become increasingly costly to run, and with different outcomes. We examine the two scenarios below.

Electricity policy and groundwater use: evidence from Gujarat, West Bengal and Uttarakhand states in India

West Bengal, in eastern India in the lower Ganges Basin, has a groundwater potential of 31 km^3 at shallow depths. Only 42% of the available groundwater resource is used (WIDD 2004). Agriculture uses only 6.1% of total electricity consumption (WBSEB 2006). There is an active market for groundwater. The state of Uttarakhand in the upper Ganges Basin has groundwater resources of 2.1 km^3, of which 66% is currently used (GoI 2005). Agriculture uses only 12% of the total electricity in the state, although 70% of tubewells are electric. Water markets are less developed than in West Bengal because landholdings are larger so that farmers have their own tubewells, and water is also widely available from reliable government tubewells. Gujarat, a western state of India, is outside the IGBs, but because it successfully resolved its agricultural energy problem, we include it. Gujarat has a groundwater potential of 15.8 km^3 of which 76% is withdrawn each year. Groundwater in 61% of the administrative blocks is rated by the Central Ground Water Board as over-exploited, critical or semi-critical. Until recent reforms, Gujarat had one of the highest electricity subsidies in India. The SEB made heavy losses and the quality of power supply deteriorated, especially in rural areas. Gujarat also has an active market for groundwater.

The process of reform in three states. The government of West Bengal installed remotely sensed, tamper-proof meters, which differentiate the cost of electricity during the day. Prices discourage pumping during peak hours and encourage it during the slack hours of the night. The government of Uttarakhand installed electronic meters, but uses conventional meter reading and bills a fixed low tariff of Rs 0.70/kW h, which is lower than the off-peak rate in West Bengal. In 2003, the government of Gujarat pioneered the *Jyotirgram* Scheme (JGS) to separate agricultural and non-agricultural feeders. This involved rewiring of rural Gujarat at cost of US$255 million. The government now provides high-quality, predictable, reliable but *rationed* power supply to farmers who daily get eight hours' power at full voltage on a pre-announced schedule that alternates weekly between day and night.

Impact of electricity reforms. Soon after metering in West Bengal, the pump owners (2% of households) increased their rates by 30–50%. Water buyers have to pay for dearer water and also receive supply at inconvenient hours. In Uttarakhand, tubewell owners will pay less than one third the amount for electricity than under the flat tariff, but we found that it was usually unpaid in any case. As in West Bengal, the Uttarakhand SEB will earn less revenue than before, and the very low, metered tariffs are unlikely to impact the volume of water pumped (Mukherji *et al*. 2006, 2009a).

In contrast, the JGS in Gujarat has improved the quality of village life, spurred non-farm activities, halved the power subsidy to agriculture and reduced groundwater pumping. It offered a mixed bag to medium and large farmers but disadvantaged marginal and landless farmers. Electricity use of tubewells has fallen 37% from over 15.7 billion kW h/yr in 2001 to 9.9 billion kW h in 2006. Groundwater use in Gujarat agriculture has fallen and has reduced the over-exploitation. Furthermore, JGS has created a groundwater economy that is amenable to regulation at different levels. Elsewhere in India and the rest of the world, groundwater management has largely been ineffective and costly. In contrast JGS has shown that effective rationing of the power supply can indeed act as a powerful tool for managing groundwater use for irrigation.

Laws and water resources governance

Water laws provide an effective basis for water governance at national, sub-national and basin levels. An understanding of how past laws worked can provide insights into how the current policy and legal frameworks will evolve in the future, and how well they address current needs in the water sector, which is a critical component of economic and socio-political development. Policy and legal frameworks have progressed from a focus on water development up to the 1970s towards water management in which water governance has become prominent. In India as a whole there was a flurry of legislation in the last decade, in which the water sector also took part. However, water resources are a state subject and any law regarding its management must be passed by the state concerned, for which the federal government provides guidance and model frameworks.

Analysis of laws applicable to groundwater shows greater attention to the topic across the IGBs since the 1990s (Figure 8), and it is a key issue in India at both the federal and state levels. Groundwater featured in 20 of the 25 instruments assessed for the Indian states in 1990–2009, with 15 having it as either a primary or substantial focus. While groundwater received important legislative attention, the relevant instruments adopted by different states were substantially similar in content and language. This was most obvious in three federal draft Groundwater Bills (1992, 1996 and 2005) and the closely similar 2005 bills of the groundwater legislation of West Bengal, Bihar and Himachal Pradesh.

At the federal level in India, two trends emerge. The first is the gradual move towards regulation of groundwater use. The need for limiting extraction to the amount of recharge was recognized by the National Water Policy of 1987 (Section 7.2), which also called

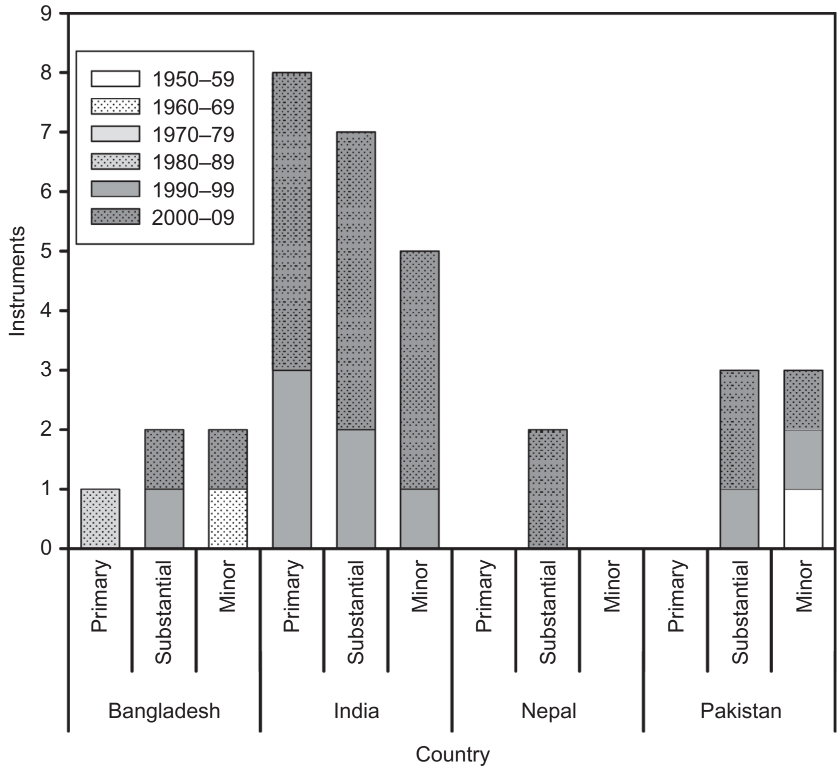

Figure 8. Dominance of groundwater laws in the countries of the IGBs (1950–2009).

for a periodic scientific reassessment of the groundwater potential, taking into account the quality of the water available and economic viability (Section 7.1). This was followed by the proposed introduction of permits for and registration of new and existing wells[1], as well as the regulation of commercial well digging in the *Draft Groundwater Bill of 1992*. The Bill also envisaged the creation of a National Ground Water Authority with the power to advise the state/union territory government to declare any area for the purposes of controlling the extraction or use of groundwater and to provide licences for further development of groundwater.

The *Draft Groundwater Bill of 1996* follows many of the provisions of the 1992 Bill, while introducing additional criteria to be considered when evaluating applications for new wells. The exceptions to the need for permits were also amended to include anyone who proposes to install a well that is to be fitted with a hand-operated manual pump or when water is proposed to be withdrawn by manual devices. The third *Draft Groundwater Bill* developed in 2005 continues the thinking of its predecessors, and introduces further criteria when reviewing applications for permission to construct wells.

The second trend, and an important addition in the 2005 Bill, is the emphasis placed on enhancing the supply side through groundwater recharge systems. The Bill envisages permits for digging new wells to include a mandatory provision requiring artificial recharge structures to be built as part of the well (Article 6.3). The proposed Ground Water Authority would also be charged with identifying areas that need recharge, and issuing guidelines for adoption of rainwater harvesting in these areas (Article 19.1). The Authority may give directions to the concerned departments of the state/union territory government to include "rainwater harvesting" in all developmental schemes falling under notified areas.

In urban areas that fall within notified areas, the Authority may issue directives for constructing appropriate rainwater harvesting structures in all residential, commercial and other premises having an area of 100 m^2 or more. Community participation through watershed management was identified as another means of facilitating ground water recharge in rural areas (Article 19.1). This is to be supported by the promotion of mass awareness and training programs on rainwater harvesting and artificial recharge (Article 19.3).

In Bangladesh, permits for wells were introduced by the *Ground Water Management Ordinance* of 1985 (Article 5.1). The Bangladesh *National Water Policy* of 1999 calls for preserving natural depressions and water bodies, underground aquifers (Section 4.6b) and the prohibition of filling in publicly owned water bodies and depressions in urban areas (Section 4.12e). It also encourages massive afforestation and tree coverage, specifically in areas with declining water tables (Section 4.12h), and proposes the regulation of extraction in identified scarcity zones (Section 4.3c).

The primary concern with groundwater in Nepal has been the dependence of large industries on groundwater extraction through deep tubewells and the need to regulate this use through licensing and effective monitoring (Section 4.2.2.4, *National Water Plan 2002*). The approach to groundwater management in Pakistan appears to be area-specific. The *Draft National Water Policy* promotes groundwater recharge wherever technically and economically feasible (Policy 8.4). It calls for the evaluation of the various technologies being used for undisturbed extraction and skimming of fresh groundwater layers overlying saline water. It also calls for optimal groundwater pumping in waterlogged areas to lower the water table (Policy 8.7), while areas with falling water tables are to be delineated for restricting uncontrolled abstraction (Policy 8.8).

The importance given to groundwater in water legislations shows the importance of this resource in the overall water resources in the IGBs.

Water, land and poverty

Poverty in the countries of the IGBs is intense and multi-faceted. Despite marked progress in the last 50 years, India still has the world's largest number of poor people. Lack of access to water and sanitation services and exposure to extreme events reinforce a cycle of vulnerability. Given that 90% of the poor live in rural areas, poverty is still a rural phenomenon in the IGBs, and agriculture is the main source of livelihood for most of the rural population in the countries of the IGBs. Thus reducing rural poverty through improving agricultural income is a major pathway for poverty alleviation in the IGBs. Adequate access to reliable water and quality land resources are crucial for an increase in agricultural productivity. With increasing pressure on limited land resources, however, enhancing the value of agricultural productivity per unit of water is crucial for the reduction of rural poverty. But the spatial linkages between poverty and WP are not clearly understood. We need this knowledge to design appropriate and geographically targeted interventions for increasing WP and reducing rural poverty.

Spatial and temporal variation of poverty

Low ranking of the human development index (HDI) of the four riparian countries – India (134), Pakistan (141), Nepal (144), Bangladesh (146) (UNDP 2008) – shows the plight of the progress of health, education and economic growth in the IGBs. Unfortunately, these values are far below those of other Asian countries. The headcount ratio (HCR, the fraction of the population below the official poverty line) of the riparian countries of IGBs has lately shown some improvement, however. In India, income of more than half the population was below the poverty line before the mid 1970s. HCR has decreased since then, to about 36% by 1993, and 26% by 2000. About 21% of the Indian population still lived below the poverty line in 2006. In Pakistan, the HCR increased in the latter part of the 1990s, but has since declined. About 22% of the population in Pakistan remained poor in 2005. In Nepal and Bangladesh, about 31% and 40% of the population were poor in 2003 and 2005, respectively. In spite of these gains, the poverty associated with high rural population is a major concern in all four countries. The depth and severity of poverty in all demographic groups in the four countries of the IGBs have declined over the last decade, however. Pakistan still has a high poverty gap index and squared poverty gap index, indicating that the income of a large part of the poor population is still well below the poverty line, which is highly likely to be in chronic poverty in the near term. The severity of poverty in Bangladesh and Nepal is comparatively lower, indicating smaller inequities of the income amongst the poor.

Poverty maps show large variations of poverty across the region. The HCR is relatively lower in north and northwestern parts of the IGBs (Figure 9), which mainly includes the northern part of Pakistan and the Indian Punjab, parts of Rajasthan in the Indus Basin and Haryana and the western parts of Uttar Pradesh of India, and Kathmandu region in Nepal in the Ganges Basin. The low HCR regions in India and Pakistan are known to have high agricultural productivity and growth, and poverty in these regions, especially in rural areas, fell much faster than elsewhere. In Nepal, areas of low poverty are concentrated in urban centres. The HCR is high in the southern and eastern parts of the IGBs, consisting of states of Bihar, Chattisgarh, Jharkand, and the eastern part of Uttar Pradesh, and Madhya Pradesh in India, the southwest divisions of Bangladesh, and all Nepal Living Standard Survey regions except Kathmandu in Nepal in the Ganges Basin, and southern Punjab, North West Frontier (NWFP), Sind, and Baluchistan provinces in Pakistan in the Indus

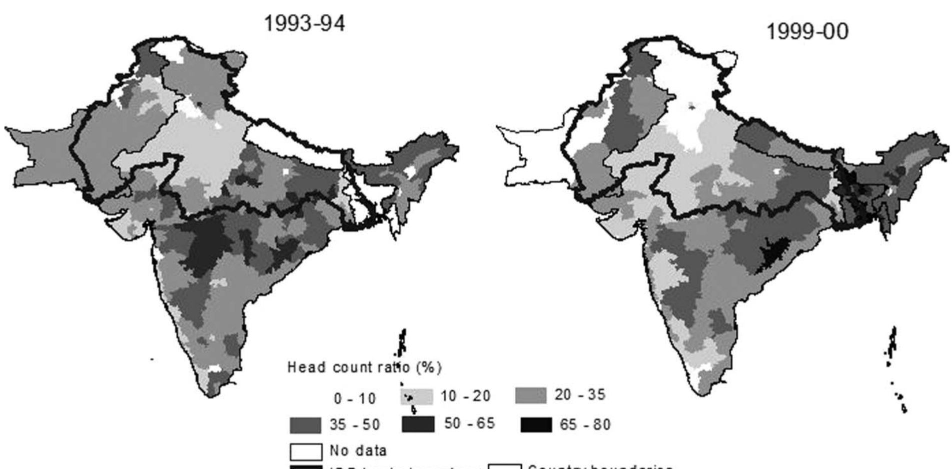

Figure 9. Poverty maps across national sample survey (NSS) regions in India, districts in Pakistan, and *zilas* in Bangladesh showing changes over the last six years of the 1990s.

Basin. Many of the rural poverty hotspots, i.e. those on the third and fourth quartile of the HCR distribution, are clustered in the eastern Ganges Basin.

Water–land–poverty nexus (NWLP)

Poverty is both a cause and an effect involving many factors. The agriculture sector contributes only about 20% of GDP in India, Bangladesh and Pakistan but provides livelihoods to more than 60% of the rural population. Our hypothesis is that growth in agriculture will reduce the incidence of rural poverty in many parts of the IGBs. Among the poorest Indian states in the Ganges Basin, the agriculture sector in Bihar contributes to 39% of the state's GDP, 34% in Uttar Pradesh and 28% in West Bengal. Analysis across Indian states in 1990/2000 shows that, on average, a 1% increase in GDP/person can decrease total HCR by 1.4%. Analysis based on 2004/5 data shows that a 1% increase in overall GDP and in agriculture GDP should contribute to a reduction of 0.96 and a 1.19% reduction of total and of rural poverty. This is further evidence that there is a large scope for reducing rural poverty through growth in agriculture, which in turn can have a large impact on reducing overall poverty in the IGBs.

Linkages between water and poverty

Access to irrigation, especially through groundwater, gives a greater control of water supply. A reliable supply of irrigation water is a key determinant for better use of inputs, such as improved seed varieties, machinery, fertilizer and pesticides. Inputs increase productivity and income, and reduce poverty. This is clearly the case in Punjab in the Indus Basin and Haryana in the Ganges Basin (Figure 10), where irrigation, much of it from groundwater, covers a large part of the cropped land. These two states have some of the lowest rates of rural poverty. There are some exceptions, however. Although not as high as in western parts of the IGBs, access to irrigation in the eastern Ganges Basin (comprised of Bihar, eastern Uttar Pradesh) and in western Bangladesh is substantially high, but poverty is also high. Low productivity due to recurrent floods and inadequate infrastructure, such as roads, markets and electricity, are major constraints. Access to irrigation is low in West Bengal and northern Madhya Pradesh, and a large part of the rural population depends on rainfed agriculture. Recurrent droughts are a major constraint on high productivity.

Linkages between land and poverty

While the incidence of poverty among the marginal to small landholders in central and eastern Ganges Basin states (Bihar, West Bengal, Uttar Pradesh and Madhya Pradesh) is very high, it is not strikingly lower among the larger landholders in these states. In comparison, poverty among the medium to large landholders in the states of western Ganges Basin is almost non-existent. Poverty among the landless in Pakistan and Bangladesh is even worse. In Bangladesh, more than 50% of landless people are poor, and the poverty among small landholders is three times higher than among large landholders. Reduction of poverty among the landless was very slow in Bangladesh, where 61% of the landless rural population was poor in 1988/89 (Ravallion and Sen 1994). This only decreased to 53% by 2000 and to 49% by 2005 (BBS 2006). The incidence of poverty in the near landless (0–0.5 ha) and marginal landholders (0.5–0.7 ha), 48% and 33%, are more than twice the poverty levels of small (0.7–1.1 ha) and medium (1.1–3.0 ha) landholders, respectively. Moreover, rural poverty in Bangladesh is high in both lowland and highland areas (Kam *et al*. 2005). Hence land ownership, holding-size and land-quality aspects are closely associated with rural poverty in Bangladesh.

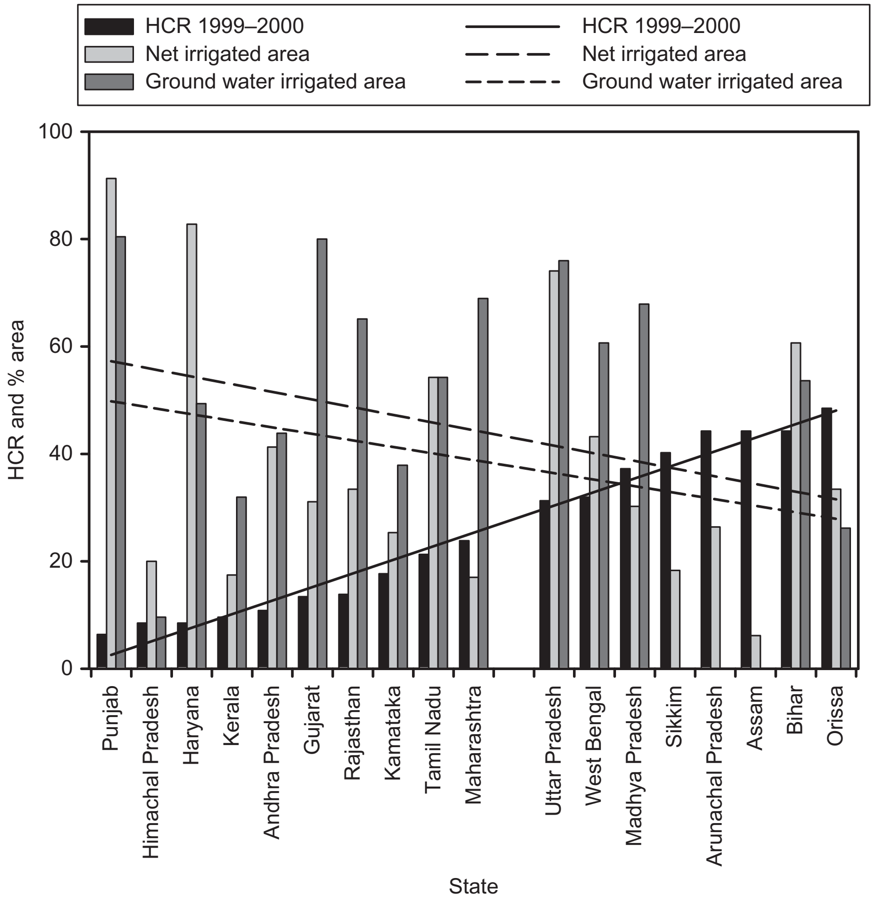

Figure 10. Headcount ratio in rural areas versus net irrigated and groundwater-irrigated area in Indian states.

In Pakistan, more than half the landless population whose livelihoods depend on agriculture, are poor (Anwar *et al*. 2004). Skewed land ownership, where two thirds of the population has no access to land and another 18% possesses small agriculture landholdings (<2.25 ha), is a major determinant of poverty in Pakistan. In Nepal, however, more than half the population classified as landless to small landholders are poor, but poverty among the large landholders is not strikingly lower (Chhetry 2001, Pant and Gautam 2008). Land productivity is a major factor that separates the rural poor from non-poor in Nepal.

Although access to irrigated land is a major determinant of decreasing rural poverty, intensive irrigation could also contribute to land degradation and threaten the very benefits that irrigation has delivered to rural people by lowering productivity and profitability. Degraded lands in turn contribute to low productivity and profitability. There is also high frequency of poverty among those who use wasteland for agriculture. Furthermore, lack of access to safe drinking water and sanitation, another dimension of human deprivation, is related to poverty (Abeywardane and Hussain 2002). Over 299 million people or 31% of the rural population in the countries of the IGBs lack access to safe drinking water (UNDP 2008), and over 796 million or 84% of the rural population lack access to safe sanitation.

Water–land–poverty nexus (NWLP) analysis at the household and district level

In our analysis we used a logit regression (LR) model, combining explanatory variables extracted from secondary data on households and administrative units, to understand NWLP at the household and district level. The LR model examines the probability (P) of a person being in poverty given the socio-economic status, assets of households, and cropping patterns, crop productivity, land tenure and size of holding, water sources and irrigation patterns, and level of infrastructure development of the administrative district. We extracted the data for this analysis from the National Sample Survey Organisation (NSSO) 61st round survey in 2004/5, which contains 32,230 household records in 280 districts in 16 states or union territories of India. We outline some of the important observations below.

Agriculture-related economic activities are still the dominant form of livelihood of the rural population. Reduction of rural poverty can be accelerated in a two-track approach: the pro-poor agriculture growth interventions can still play a major role in reducing poverty in the agriculture-operator households, and improving skills and enhancing opportunities for employment in the non-farm sector can reduce poverty among the agricultural labourers.

In the IGP in India, growth in agriculture is significantly related to the growth in yield of food grains, and crop diversification. The existing grain yields range from 0.9 t/ha in the central region in Bihar to 4.5 t/ha in the western Punjab and provide a strong indication of the magnitude of the scope for growth in agricultural productivity. Districts with a high percentage of the area growing fruits and vegetables are also significantly associated with low HCR.

Rainfall, access to irrigation, irrigation using groundwater, and WP of irrigated agriculture are all significant in explaining the variation of HCR in the IGBs, with households having large areas of irrigated crops being significantly less poor. The incidence of poverty of households without land and without irrigation are similar, but decrease with better access to irrigation.

Better access to groundwater, in general indicating a reliable irrigation supply, is also associated with low poverty. The positive interaction of WP and the extent of the irrigated area also show that by increasing access to irrigation, increases in productivity can accelerate poverty reduction in areas with low levels of water endowment.

Considering the size of the landholding shows that a large number of marginal and small landholdings are associated with high levels of rural poverty across districts. Among the poor households, 33% have no access to land and a further 54% have only marginal to small landholdings. Moreover, many of these small landholdings are highly fragmented and therefore seem to be a major reason for low inputs and productivity. These areas are the hotspots of rural poverty in the eastern IGBs.

Access to infrastructure such as road, markets and electricity also has a major influence in reducing poverty. Districts with higher road density are associated with low HCR. Lack of markets is also a main determinant in the regions with high rural poverty.

Water–land–poverty nexus: lessons from case studies in India, Pakistan and Nepal

We also conducted case studies in India, Pakistan and Nepal to examine the NWLP at the household level, using questionnaire surveys. The survey was based on three separate questionnaires responding to the village and household profile and to fragmentation of the cultivated landholding. In India, we conducted the survey in three least progressive districts of Bihar, Vaishali, Darbhanga and Munger. In Pakistan, the case study site was

Rechna Doab and in Nepal, we conducted the study in four villages of Morang and Sunsary districts. We summarize the inferences from the case studies below.

Property rights and the status of water resources

In India, more than two thirds of the respondents purchased agricultural water through informal trade mechanisms, with 68% buying water from local groundwater markets, while 20% have their own pump and only 6% make use of public canal water. In Pakistan, however, each farmer had an individual allocation of a share in the canal network. In Nepal, use of public canal water was almost universal with only minimal ownership of tubewells.

Water volume allocation in property rights schemes

In India, about two thirds of the buyers and all the water owners make exclusive use of a specific water source without combining it with any other additional source. In the case of canal irrigation, however, only 20% depended solely on the canal supply. In Pakistan, the majority of tubewell owners cover only a small amount of the landholdings through this source. In Nepal, all the farmers depend only on a single source of water, either canal water or groundwater.

Farmers' perspective towards agricultural water use

Indian farmers claim that lack of credit is the major reason for low productivity, closely followed by insufficient supplies of water, and unpredictable weather. In Pakistan and Nepal, insufficient water supply is by far the most important constraint for higher productivity. Farmers in all three countries identified improved water availability as a major factor contributing to increased productivity. Farmers are very willing to set up a groundwater market to meet their water needs, but are not able to make financial contributions for such a venture. In India, 70% of respondents agree to setting up a co-operative tubewell system. Most respondents also gave high priority to the introduction of new technologies and specialized training on methods to improve production.

Conclusions and recommendations

The waterscape of the Indus and Ganges plains is like a palimpsest. It is a landmass that was thickly populated and intensively cultivated over 2000 years ago, and carries the imprints of countless waves of hydraulic tradition. Mastering and manipulating snow-fed perennial streams and rivers for watering fertile soils has remained the secret of the IGBs' endemically high population-carrying capacity. Unfortunately, past fortunes have turned for the worse. Today India, Pakistan, Nepal and Bangladesh, the four countries that share the contiguous Indus and Ganges basins have more poor people than any other region in the world and are amongst the worst laggards in the global human development index and human poverty index. Its vast, fertile plains remain overwhelmingly rural and agricultural. Though agriculture contributes only about 20–25% to the national GDPs, agriculture as a means of livelihood provides 78% of total employment in Nepal, 63% in Bangladesh, 66% in India and around half in Pakistan. With population pressures bursting at the seams and now exceeding one billion people, the availability of cultivable land per capita, through which people eke out a living, has shrunk to around 0.1 ha. With the exception of Nepal, the internally renewable fresh water resources are much below the threshold limit and stand at 325, 688 and 1149 m^3/capita/year respectively for Pakistan, Bangladesh and the Indian parts of the Indus-Ganges plains. It is certainly no exaggeration to say that the basins of the Indus and the Ganges basins are "under extreme pressure".

We summarize below some of the important recommendations that arise from the work we have presented, which will help to improve sustainability of the resources, enhance agricultural productivity, and alleviate poverty.

(1) *Regional perspective:* From both the hydrological and socio-ecological perspectives, the opportunities, constraints, strengths and weaknesses of the Indus Basin and western Ganges Basin ("northwestern region") are markedly different from eastern Ganges Basin (eastern Indian states, Nepal Terai and Bangladesh, "eastern region"). Water and land resources are intensively utilized in northwestern region and are poorly utilized in the eastern region. Development frameworks and policies need to be regionally differentiated to ensure long-term sustainability in the northwestern region and substantially improve the productivity and economic dynamism in the eastern region.

(2) *Use and abuse of water resources:* Most of the available water resources are utilized within the Indus Basin leaving little scope for expansion; the basin is closed. The strategic options are for improving crop productivity by moving towards high-value, diversified and precision agriculture, and to release some water from the irrigation sector to meet the growing demands for domestic, industrial and environmental flows. Net discharge from the Ganges Basin (37%) accounts for more water than any other use. Additionally, the basin also has a massive and presently unutilized static groundwater resource of about 7800 km^3. The Ganges Basin countries may immediately initiate sound groundwater development and use policies that will help increase productivity, reduce climatic vulnerability and also alleviate poverty.

(3) *Improving agricultural productivity*: The average WP for the rice–wheat rotation system in the Indus-Ganges plains is low at US\$0.131/m^3 whereas the "bright spot" areas (about 5% of basin area) have high water productivity of US\$0.190/m^3. If the basin average value could be increased to the "bright spot" level, the basin could theoretically save 31% of agricultural water consumption with the same production or alternatively increase production by 31% with the same water input. This shows a great opportunity for improving productivity through a set of technical and policy interventions.

(4) *Potential interventions for improving water productivity:* As access to water resources is relatively poor in large parts of the region, the critical crop water requirements are inadequately satisfied and crops experience different degrees of water stress. Farmers need to know more about these critical growth stages so that they can improve their management of specific crops in different regions through proper irrigation scheduling. Adoption of resource conservation technologies such as reduced/zero tillage, laser land levelling, raised bed planting and direct seeding of rice need to be promoted better to realize their benefits on a wider scale. Policy measures like regulatory delay in transplanting of paddy and breaking the water–energy nexus on the pattern of the *Jyotirgram* scheme will improve groundwater governance. Multiple-use water systems in the hilly areas of the basin and the eastern region will improve productivity and alleviate poverty of the small and marginal farmers.

(5) *Policy and institutional changes:* Energy infrastructure and policies in the eastern region need to be comprehensively and immediately improved so as to empower

the millions of small and poor farmers operating at a very low level of agricultural productivity. The groundwater boards and authorities in all the four countries need to be strengthened to move further from their present role of resource estimation to planning, development and management.

(6) *Managing the water–land–poverty nexus:* Reduction of pervasive rural poverty in the region can be accelerated in a two-track approach: pro-poor interventions to increase agricultural yields will play a major role in reducing poverty in the agriculture-operator households, and improving skills and enhancing opportunities for employment in the non-farm sector can reduce poverty among agricultural labourers. Providing access to irrigation can help achieve substantial improvements in productivity, diversification and thus reduction in poverty. Higher access to groundwater is associated with low poverty. Setting up of co-operative tubewells managed by small groups of farmers may be a viable option for helping large numbers of marginal farmers with smallholdings. Areas with small and fragmented holdings are hot spots of rural poverty in the eastern region and need immediate policy changes to stimulate consolidation. Access to infrastructure such as roads, markets, electricity and quality inputs can also have a major influence in reducing poverty.

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Note

1. Small and marginal farmers will not have to obtain a permit if the well is proposed to be sunk for exclusively personal purposes (Section 6.1).

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