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Agriculture Diversification for Sustainable Groundwater Use: A Case Study in the Moga District of Punjab, India

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Abstract : This paper assesses water depletion of agricultural production in the Moga district of the State of Punjab. It particularly focuses on growth in agricultural production and stress on water resources induced by groundwater irrigation.

Rice, wheat and forage crops comprise more than 99% of the annual cropped area in Moga. Groundwater contribution to the total annual consumptive water use (CWU)—94% of 1,461 million m^3 —is so large that groundwater embedded in the production surpluses of rice, wheat and milk alone exceeds the estimated groundwater recharge in the District.

The groundwater CWU in rice production is 1.7 to 2 times higher than those of milk and wheat, and the financial value of the output of rice-wheat-milk production system is 10 and 27% lower than that of the milk-wheat and milk-only production systems respectively. Thus, the intensification of dairy production with a calculated reduction in rice area and increase in green fodder area is the most expedient way of reducing water depletion. It can not only bring the groundwater depletion to sustainable limits, but also increase the value of total agriculture production, while producing a surplus of rice for export. The optimum combination is to change annual cropping pattern of rice, wheat and fodder crops to 62, 90, and 42% of the net irrigated area from the present level of about 90, 90 and 20% respectively, and double the lactating dairy animals to 8 per 6 ha of land.

INTRODUCTION

Moga, a district in the State of Punjab in India, is a microcosm of the twin story of irrigation-induced growth and stress. Irrigation, on the one hand, was a major catalyst for the successful green revolution resulting in increases in wheat and rice productivity, and for the white revolution resulting in increases in milk production (Dhawan 1998). However, extensive groundwater irrigation that revolutionized agricultural production, is also the cause for severe water stress (Shah 2009)

The State of Punjab is considered as the seat of the Green Revolution in South Asia. The State with only 1.5% of the land area contributes 12 % of the total food grain production—230 million tonnes (Mt)—of India in 2007/08 (GoI 2009). With significant production surpluses, Punjab offers 50% of its total production each year to the national pool for maintaining stocks and operating public distribution system for the poor and food-deficit states (GoP 2010). Growth in agricultural productivity was a major driver behind the economic growth of Moga.

Underneath this agricultural success story also lies a stark reality of severe water stress. Physical water scarcity envelope the whole region, meaning that no further development of water resources is Pareto optimal (Amarasinghe et al. 2007). Groundwater development is so extensive that 79% of the groundwater assessment divisions ("blocks") in the State are now considered 'overexploited' and 'critical' (CGWB 2010). In fact, excessive groundwater depletion throughout the State is corroborated by the information derived through satellite data for the northwestern India (Rodell et al. 2009).

Many recent interventions implemented in the State envisage reducing groundwater over abstraction. The recently enacted "Punjab Preservation of Subsoil Water Act of 2009", which aims to delay paddy transplantation, was a major policy intervention by the Government of Punjab (GoP) for reducing overabstraction of groundwater. Among other interventions, laser land levelling, resource conservation technologies, changing cropping patterns, introducing low water consuming varieties, etc., are expected to reduce water use (Singh 2009). However, the impacts of such measures on agriculture water depletion are not well understood.

Rice and wheat, mainly for food, and forage crops for animal feed occupy more than 99% of the cropped area in Moga. The report focuses in particular on growth in agricultural production and stress on water resources induced by groundwater irrigation. The major objectives of this study are to:

- Assess water depletion in the process of agricultural production in the Moga District of the State of Punjab
- Examine the impacts of water depletion in various agricultural production systems on groundwater use, and
- Propose improved water management practices that farmers can use to reduce water depletion, and enhance water productivity

After a brief profile of Moga and groundwater development in the section 2, the concept and methodology used in the assessment of the water depletion of milk, rice, and wheat production in Moga are presented in section 3. The estimates of CWU of milk, rice, and wheat are presented in section 4. This is followed by an analysis of total CWU and their impacts on the water resources of Moga in section 5. An intervention and its impacts on reducing CWU are discussed in section 6 and cconcludes the paper with a discussion of options available for policymakers and farmers for achieving sustainable water use in Moga and similar agro-ecologies elsewhere in section 7.

MOGA DISTRICT AND ITS GROUNDWATER DEVELOPMENT

Demography and Food Security

The Moga District, with 5 administrative blocks (Table 1) is the eleventh largest of 20 districts in the State of Punjab in India. Average annual rainfall is 498 mm. Average daily temperatures varies from 5 to 48°C.

Most of the Moga population live in rural areas (Table 1) and depend on agriculture for their livelihoods.Rice and wheat are the main crops during the *Kharif* and *Rabi* seasons, respectively. Small areas are also under cotton and maize in the *Kharif* season, and gram and potatoes in the *Rabi* season. Fodder crops, such as sorghum (jowar), maize, millet, barley, berseem and oats, provide year-round green fodder feed to large cattle and buffalo populations and for a small population of other animals (goats, sheep, horses, etc.).

Although a substantial part of the milk produced is consumed locally, Moga also has significant milk production surplus. The surplus milk is procured by local vendors, milk contractors and the milk collection centers such as Nestle. Nestle started its operations in Moga in 1961 with 180 farmers and 511 liters of milk procured through 4 collection centers. By 2009, Nestle has linked with about 105,000 farmers and is now handling 500,000 to 1.3 million liters of milk collected daily through 2,800 collection centers in the Moga and neighboring districts

Groundwater Development

Almost 90% of the land area in the district is under cultivation, and all cultivated area is irrigated (DoAAD 2009). Of the net irrigated area

Table 1 : Area, demography and water availability of blocks in the Moga District.

Block name	Land area	Number of villages	Total population	Rural population	Number of families[1]	Net irrigated area	Net ground water recharge	Ground water withdrawals for irrigation	Ground water withdrawals for all uses
	1,000 ha	#	1,000s	1,000s	1,000s	1,000 ha	mcm	mcm	mcm
Bagha Purana	57.3	47	220	176	30	49.6	257	444	447
Dharamkot	54.9	150	212	169	29	48.9	365	502	506
Moga 1	39.8	48	167	134	23	33.4	209	422	428
Moga 2	33.3	46	126	101	17	29.0	208	386	391
Nihal Singh Wala	38.2	39	170	136	24	33.9	181	392	394
Moga	223.5	330	895	716	123	194.8	1,220	2,146	2,166

only 2.4% is canal irrigated, and 53.5% is groundwater irrigated, and the remaining area is under conjunctive irrigation of canals and tubewells. Groundwater is provisioned through 49,662 electric motor pumps and 7,212 diesel pumps. A recent study shows a negative groundwater balance in all blocks (CGB-NWR 2009).

Water is required in large quantities and is an important component of the milk value chain: fodder and feed production, maintenance of animal population, milk commodity, industrial production of dairy products, etc. A better understanding of these processes helps to ensure more water-efficient crops and milk production. The next section of the report deals with the estimation of water depletion of milk and crop production in the Moga District.

CONCEPT, METHODOLOGY AND DATA

Concept

The total water depletion in the production process has two components (Figure 1), namely: i) water depleted within the production area, and ii) water embedded in other inputs used in the production process. These are also often referred to as 'internal' and 'external' water footprints (Hoekstra (2003). The latter ('external water footprint') is also called 'virtual water' (Allan 1998)); The internal depletions when aggregated over all commodities such as fodder, rice, wheat and other crops and services (drinking, bathing and servicing of animals) indicates the extent of depletion of available water resources within the boundaries of the district.

The internal and external water depletion has three sub-components.(Equation 1). The first and second components account the evapotranspiration from the effective rainfall and irrigation. The third component is the depletion due to water pollution. The three components are generally called "green", "blue" and "grey" water footprints in the water footprints literature (Hoekstra 2003).

The first and second component, ($CWU^{Effectiverain}$, $CWU^{Irrigation}$), contains only the beneficial CWU of crop and milk production.

The third subcomponent- ($CWU^{Pollution}$) indicates the extent of water pollution due to various input uses during the production process. This component is estimated as the quantity of freshwater that is required to bring the polluted water to ambient water quality standards (Hoekstra et al. 2009).

The total water depletion includes water depleted *directly or indirectly* in the production process. Milk production has a significant indirect

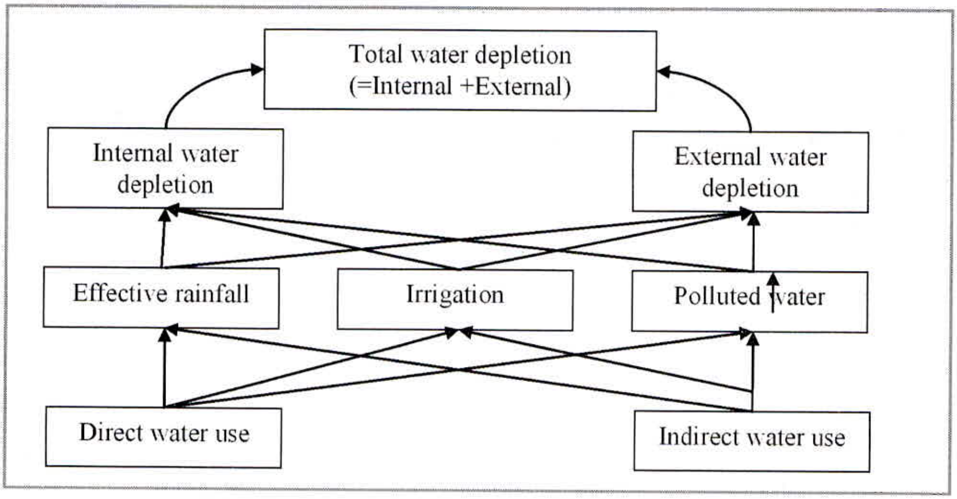

Fig. 1 : Process of estimation of water depletion

$$\left.\begin{matrix} Internal \quad water \quad depletion \\ External \quad water \quad depletion \end{matrix}\right\} = CWU^{Effective\,rain} + CWU^{Irrigation} + DEP^{Pollution} \qquad (1)$$

water use component (Table 2). Direct water use in milk production is only the water depleted through drinking water and bathing of animals. Direct water used for producing green and dry fodder and other animal feed are indirect water uses in milk production.

Table 2 : Contributions from direct and indirect water use to components of water depletion

Water depletion			Direct water use	+	Indirect water use
Milk	Green	=	na	+	CWU from soil moisture in fodder and other feed crops
	Irrigation	=	Drinking/servicing of animals	+	CWU from irrigation in fodder and other feed crops
	Grey	=	Water required where its quality deteriorates below drinking water standards due to manure	+	Water required where its quality deteriorates below drinking water standards through input use or in by-products
Crops	Green	=	CWU from soil moisture in crop production	+	na
	Irrigation	=	CWU from irrigation water in crop production	+	na
	Grey	=	Water required where its quality deteriorated below drinking water standards from input use or in by-products	+	na

Notes: [1] Crops are rice, wheat, green fodder (sorghum, maize, berseem, oats etc.); na - not applicable

Rice and wheat production mainly have a direct water use. Indirect water use through seeds and other inputs in general is much smaller and hence can safely be assumed to be negligible for computational purposes.

Estimating Water Depletion

Green and Irrigation Consumptive Water Use of crops

If rainfall meets the full crop water requirement, then CWU from effective rainfall ($CWU^{Effectiverain}$) equals actual evapotranspiration (ETa) in four crop growth periods (initial, development, mid- and late stage) (Allan et al 1998).

If rainfall is insufficient to meet full crop water requirement, the $CWU^{Effective\ rain}$ equals the effective part of rainfall at the root zone. When irrigation meets a part of the deficit of crop water requirement, the beneficial evapotranspiration component of irrigation is the $CWU^{Irrigation}$.

Notes: [1] Crops are rice, wheat, green fodder (sorghum, maize, berseem, oats etc.); na - not applicable

Estimating irrigation withdrawals

Irrigation water withdrawals (Q, m^3) include both surface water and groundwater, and are estimated as:

$$Q = \{A_{canal} \times NI_{canal} \times d_{canal} + A_{gw} \times (pd_{gw} \times NI_{gw} \times h_{gw})\} \times 10^4 \qquad (2)$$

where: A_{canal} and A_{gw} are canal and groundwater irrigated area (ha); NI_{canal} and NI_{gw} are number of irrigation applications per unit area; d_{canal} is average depth of a canal irrigation application (m); h_{gw} is average number of hours of groundwater pumping per irrigation (hours); and pd_{gw} is pump discharge (m^3/hours). In conjunctive irrigation, A_{canal} and A_{gw} are the same (Michael 2001).

Data and assumptions

Information required for estimating the CWU in m^3/tonne of milk and other crops in Moga were not available in published databases, so it was necessary to conduct a household questionnaire survey. The primary data collected in the questionnaire survey include milk productivity and feed supply patterns for lactating cows and buffaloes, the cropping and land use patterns of fodder and other crops (irrigated area under canal water, groundwater and conjunctive use), crop growth periods, crop productivity, water withdrawals (number of irrigations and duration of each withdrawal), tubewell details and fertilizer and other input use for food crops and green fodder at the farm level.

A sample of 300 farmers in 10 villages from 5 blocks were selected for the survey. Primary data, collected between October and December 2009, relates to 2008/09 *Rabi* and *Kharif* seasons.

Survey data are used to estimate all components of CWU in terms of water depletion per unit of production (m^3/tonne) across farms. The weighted averages of CWU and other data across farms from the sample survey are then combined with secondary data of the total number of lactating cows and buffaloes (DoDL 2009) and total crop production in Moga (DoAAD 2009) to estimate the total CWU (m^3/year) components in Moga.

IWMI Water and Climate Atlas (IWMI 2000) was the source of ETp and P75 data. The crop coefficients and the lengths of the growing periods (initial, development, mid-season and late-season) of rice, wheat and green fodder crops (sorghum, maize, berseem and oats) are taken from the FAO AQUASTAT database (FAO 2010).

The following assumptions are made in calculating the CWU.

- Drinking and bathing water requirements of lactating cattle or buffaloes is assumed to be

100 liters/day/animal and is fully provided by groundwater (Singh et al. 2004).

- Crop yields for fodder crops were not available from the questionnaire survey. The yields of major fodder crops, sorghum, maize, berseem and oats are assumed to have lower and upper limits of 35-70, 35-45, 100-120 and 45-55 tonnes/ha, respectively, for estimating the range of production possibilities from current cropping patterns (ICAR 2009).
- Concentrate contributes to both internal and external water depletion. The composition of a typical concentrate shows that about 40% of the cost of different components used in the concentrate formula is from within Moga, while the other 60% forms imports to Moga. This paper assumed similar percentages of water consumption within Moga and virtual water imports from outside moga. The CWU of the concentrate formula is assessed at 1.24 m^3/kg.

CONSUMPTIVE WATER USE OF RICE, WHEAT AND MILK (M^3/TONNE)

The average CWU of rice and wheat production are 1,380 and 554 m^3/tonne, respectively (Figure 2). Groundwater contributes 95 and 92% of the irrigation CWU of rice and wheat. The total CWU of milk production is 940 m^3/tonne, and the internal and external components are 613 and 327 m^3/tonne respectively.

The internal groundwater CWU of rice is 2.0 and 1.7 times those of wheat and milk, indicating that rice is a major contributor to Moga groundwater depletion.

In fact groundwater contributes to more than 92% of the irrigation of rice in all land use patterns (Table 3). In wheat, groundwater contributes to more than 87% of the irrigation. All fodder area is only irrigated from groundwater. Estimated irrigation water use efficiency, the ratio of irrigation CWU to withdrawals, is significantly lower for rice (42%) than for wheat (79%). As a result, rice production also has a significant non-process non-beneficial evaporation, estimated to be in the order of 143 m^3/tonne for rice against 23 m^3/tonne for wheat.

Green fodder, dry fodder, feed concentrates are the main feed for indigenous and cross bred cows and buffaloes. Water consumption in feed accounts 98% of the internal CWU (Table 4). Only concentrate feed contributes to external CWU,

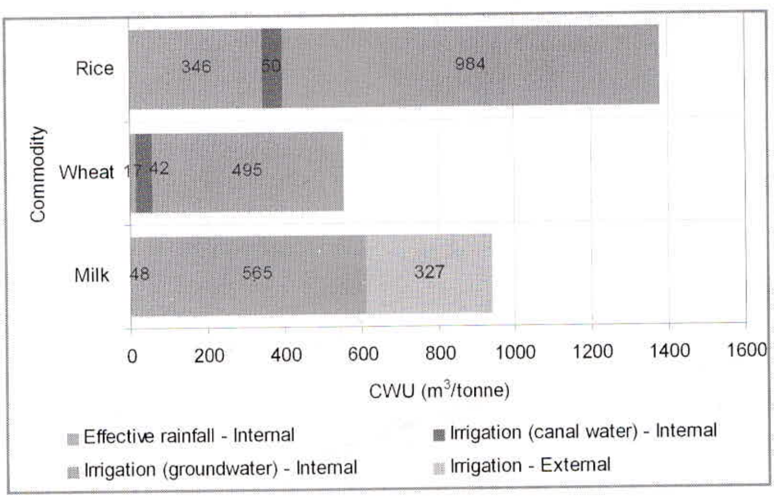

Fig. 2 : Consumptive water use of rice, wheat and milk production.
Source: Authors' estimates using the sample survey in the Moga District.

which accounts 34.8% of the total CWU in milk. A major contribution to internal component is from indirect water use through feed consumption (Table 4). Drinking/servicing water use of animals is only 2% of the total CWU.

Table 3 : Factors of rice, wheat and fodder production in Moga

Factor	Crops		
	Rice	Wheat	Fodder[1]
Area - % of net irrigated area	91.2	89.5	8.10
Land use patterns			
- Only GW irrigated area (%)	29	30	100
- GW and conjunctive water use (%)[2]	24	23	-
-Only conjunctive water use area (%)	47	47	-
Productivity (tonne/ha) – Average	4.96	4.77	124-199
- Standard deviation	(0.66)	(0.52)	
ETa (mm)	671	268	727
Effective rainfall (mm)	167	8	132
Net evapotranspiration (mm)	504	260	595
Share of groundwater in irrigation (%)			
- GW only area	100	100	100
- GW and conjunctive water use area	97	93	-
- Only conjunctive water use area	92	87	-
Net irrigation requirement as a % of irrigation withdrawals	42 (60)[3]	70	110

Source : Sample survey in Moga

1- Weighted average of all fodder crops grown year-around.

2- These farmers reported part of their irrigated area use only groundwater and other part uses both groundwater an canal water.

3- The ratio is 60% if net irrigation requirement include 200 mm percolation

Table 4 : CWU of feed and drinking/servicing water requirements of lactating animals

Factor	Feed consumption			Drinking/ servicing
	Green fodder	Dry fodder	Concentrates	
Consumption (tonne/animal/year)	9.7	3.5	1.7	36.5[1]
Internal CWU (m^3/tonne)	196	184	218	15
External CWU (m^3/tonne)	-	-	327	-

Source: Sample survey; 1- Estimated at 100 liters/animal/day

TOTAL WATER FOOTPRINTS AND IMPACTS

Groundwater depletion

Groundwater contribution to irrigation CWU of rice and wheat are 984 and 495 m^3/tonne leading to total groundwater depletion of 854 and 415 mcm/year in rice and wheat production, respectively (Table 5).

In milk production, internal irrigation CWU is estimated as 565 m^3/tonne. However, dry-fodder from wheat also contributes to part of this component. To avoid double counting in the estimation of the total CWU, irrigation component of dry-fodder[1] is deducted from the internal CWU of milk. The total irrigation consumptive use of milk production[2] is estimated to be 113 mcm/year (Table 5), for which groundwater contribution is 100%.

Overall, the groundwater footprints of milk, rice and wheat is about 1,382 mcm/year, which is 162 mcm over the annual natural recharge of groundwater resources in Moga.

Value of Production

'Milk-only' production system generates more value of output than other systems including rice and wheat (Figure 3). Three main production systems: *milk-wheat-rice; milk-wheat* and *milk only* are considered for this comparative analysis. The first set of three bars indicates the contribution of rice, wheat and milk to the gross value of production per ha of net irrigated area (US$/ha). The second set of three bars indicates the contribution of rice, wheat and milk to the gross value per m^3 of groundwater irrigation CWU (US$/ m^3).

The gross value of output per land use of *milk only* or *milk-wheat* production systems — 4,220 and 3,422 US$/ha— are far superior to the gross value of output of—3,080 US$/ha— the most common production system *milk-wheat-rice.* However, due to higher cost of production, the relative differences of net value of outputs[1] may vary.

Table 5 : Rice wheat and milk production and groundwater use

Factor	Unit	Rice	Wheat	Milk
Total production in 2008/09	1,000 tonnes	868	838	292
Value of production[1]	%	45	31	24
Total consumption	1000 tonnes	2.8	93.6	126
Total consumption[2]	1000 tonnes	865	744	165
Production surplus/ deficit	1000 tonnes	865	744	165
Groundwater irrigation CWU	m^3/tonnes	984	495	387
Total groundwater irrigation CWU	mcm	854[2]	415[2]	113[2]
Virtual water[1] content of the surplus	mcm	1,194	412	72
Virtual groundwater content (mcm	mcm	852	368	64

Sources: Net groundwater resources and net irrigated area are from (DoAAD 2009); milk production is estimated by combining the milk cattle and buffalo population figures of the 18th Livestock Census (DODL2009), with the milk productivity estimated from the Moga sample survey; GOI 2009 for consumption figures; and the Moga sample survey for CWU estimates

Notes: [1] Value of production is estimated at INR 14 and INR 10/kg of rice and wheat, and INR 17.50 and INR 24.00/kg of cattle and buffalo milk

[2] Average per capita consumption figures of the State of Punjab are used for estimating total consumption. Per capita consumption of rice, wheat and milk are 0.0755, 8.94 and 11.875 kg/month in rural areas and 1.023, 7.792, 11.358 kg/month in urban areas, respectively.

While, green fodder accounts for two-thirds of the biomass of feed for lactating animals, wheat straw contributes to 26% of the biomass of total feed. Feed concentrate accounts for 8% of the remaining feed biomass. Thus, although the value of production per unit of irrigated area is a good indicator for comparison of benefits of rice and wheat production, the value of production per hectare of fodder area masks the indirect benefits accrued from the wheat dry fodder. This anomaly in value estimation per ha can be eliminated by considering the aggregate value of output per unit of net irrigated area and per unit of water consumed, as indicated in Figure 3.

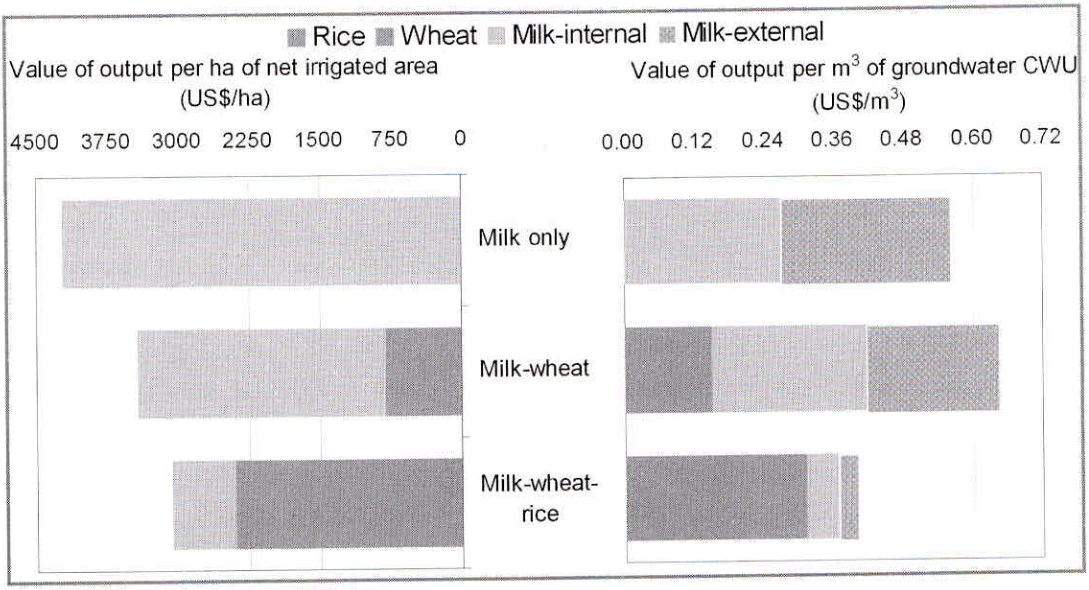

Fig. 3: Gross value of production per unit of land used and per unit of groundwater irrigation CWU across production systems.

Source: Authors' estimates using the sample survey in Moga District

[1] *Contribution of wheat dry-fodder to the CWU of milk is about 178 m³/tonne (37 and 141 m³/tonne of internal green and irrigation CWU).*

[2] *Total milk production is estimated using the figures of the number of cattle (indigenous, crossbred) and buffaloes in different blocks, which were taken from the livestock census in 2008/09 (DoDL 2009); and milk productivity estimates were taken using the sample survey in the Moga District.*

[3] *The net value of output is the difference between gross value of output and the cost of production. This study did not estimate the cost of production at the farm level. However, secondary data shows that the average cost of rice and wheat production in the State of Punjab are US$ 753 (INRs 33,885), US$ 603 (INRs 27,149)/ha respectively (See GOI 2007 for estimation explanation). Also, Hemme et al (2003) estimated that the cost of milk production of farms growing crops and forage in the State of Haryana, India in 2001 was around US$ 150/tonne. As wheat production is the only source for dry-fodder feed, it is assumed that cost for milk production in farms not growing wheat is 25% higher. With 4.2% annual rate of increase of cost of production, the cost of milk production in 2008/09 is estimated as US$ 200 for wheat and green fodder growing farms, and US$ 250 in only green fodder growing farms. Based on these average cost of production data, the net value of output of milk-wheat production system (1,822 US$/ha) is the highest, followed by milk only (1,714 US$/ha) and milk-wheat-rice production systems (1,540 US$/ha).*

In terms of gross value per groundwater consumptive use, *milk-wheat* or *milk only* production systems are superior to the production system including rice. The gross value per CWU of *milk-wheat-rice*, production system of 0.40 US$/m^3 is only 62% of the value of *milk-wheat* (0.64 US$/m^3) or *milk only* (0.56 US$/m^3) production systems. The water used in dry-fodder is already included in the wheat production. Thus, *milk-wheat* production system has higher value of output with respect to groundwater CWU than *milk only* production system.

A strong implication of these estimates is that farmers in Moga can diversify their agricultural production systems without significant loss of the value in production while reducing pressure on scarce groundwater resources. As wheat is an important source for dry fodder, a proper combination of wheat and fodder area can optimize the returns to land as well as water depleted. However, rice production is also contributing to the food security of a large population outside Moga. Thus, the intensification of dairy production, with a calculated reduction in rice area to compensate for increasing requirements for green fodder, can bring the groundwater depletion to sustainable limits, while producing a surplus of rice for exports. The trade-off of these scenarios will be assessed later.

Virtual Water Export

The level of production of rice, wheat far exceeds the demand for local consumption by the Moga population (Tables 5). At present, the local demand for rice, wheat and milk are only 0.3, 11.2 and 43.3%, respectively, of the total production. Since groundwater is the dominant source of irrigation, most of the groundwater CWU in agriculture production accounts for the virtual water exports from Moga. A substantial part of the CWU, especially from groundwater, is exported as virtual water from Moga to other regions.

The virtual groundwater content in rice, wheat and milk surpluses are 852, 368 and 64 mcm/year. The total net virtual groundwater export through rice, wheat and milk from Moga is 1,284 mcm/year, which is 64 mcm more than the natural groundwater recharge. Rice contributes to two-thirds of the virtual groundwater exports, while wheat and milk exports contribute to 29 and 4%, respectively, of the virtual groundwater exports.

Given the differences of value of production and virtual water exports, it is clear that reducing surplus agricultural production offers the greatest opportunity for keeping the water depletion within the natural groundwater recharge levels. This can be done either by reducing the surpluses of rice, wheat or milk individually or as a combination.

If reduction in water depletion is to be achieved only by reducing rice exports, it means reducing the virtual groundwater export of rice by at least 162 mcm, or reducing the production surpluses of rice by 165,596 tonnes. At the current rate of rice yield, this reduction is equivalent to 19% of total rice production. In contrast, if wheat surpluses are to reduce to bring groundwater depletion under natural recharge limits, the total wheat production has to be reduced by 16%, and milk production has to be reduced by 36%, which in value terms could have a big impact for the farmers of Moga.

REDUCING GROUNDWATER CWU

Many of the physical interventions practiced in Moga intended to reducing irrigation water withdrawals, but not the total CWU. At present, the total groundwater CWU from dairy, wheat and rice production alone exceeds the natural groundwater recharge limits. A major reduction of CWU cannot be achieved without changing the production patterns. As milk and wheat production have the lowest internal groundwater irrigation CWU, intensification of dairy production with adequate wheat and green fodder area is the ideal choice for Moga.

The combination of milk, wheat and rice production for making agricultural production financially and hydrologically viable in Moga is assessed next. This is assessed by developing various scenarios of cropping and dairy animal raising patterns.

The gross value of output of crop and milk production under the present average conditions (base scenario) is US$ 1,576/ha, but it depletes 162 mcm of groundwater over the natural recharge limits.

The 'base scenario' (Table 6, first row) shows the present average conditions. These are:

- Ninety-percent of the NIA are under rice and wheat in the *Kharif* and *Rabi* season, respectively, and 10% of NIA is under year-round fodder crops.
- Number of lactating dairy animals raised on a 6 ha of land area is 4, comprising 1 crossbred cow and 3 buffaloes. Along with them, 50% more non-lactating dairy animals are also raised.
- Land productivity of rice and wheat are 4.96 and 4.77 tonnes/ha, respectively; green fodder productivity is 110 tonnes/ha; dry-fodder weight of wheat is 1.75 times that of the primary product; and milk productivity of cattle and buffaloes are 10.3 and 6.5 liters/day/animal, respectively.
- Internal consumptive groundwater use of rice and wheat are 984 and 494 m^3/tonne and groundwater irrigation depth on fodder area is 304 and 191 mm/ha in *Kharif* and *Rabi* seasons, respectively.
- Drinking water of lactating animals is 100 liters/day/animal and per capita consumption of green, dry fodder and concentrate is 9.7, 3.5 and 1.7 ton/year/animal, respectively.

Table 6 also shows the hydrological and financial implications of various alternative scenarios of cropping patterns and dairy animal population and their implications on the net value of output and groundwater footprints. The alternative scenarios assess the changes in net

Table 6. Changes in value of production, groundwater CWU under various scenarios of cropping and dairy animal rearing patterns.

Scenario	*Kharif* season		*Rabi* season		Number of lactating animals/ 6ha land area		Annual net value of output		Goundwater CWU	
	Rice	Fodder	Wheat	Fodder	Total	Cross-bred cows	Per ha of net irrigated area	Change – (% of base)	Total	Change from base
	%	%	%	%	#	#	US$/ha	%	mcm	mcm
Base scenario	90.0	10.0	90.0	10.0	4	1	3,124	-	1382	-
Alternative scenarios										
A1	0.0	10.0	90.0	10.0	4	1	1,752	-1,372	541	-845
A2	70.0	10.0	90.0	10.0	4	1	1,421	-305	1,220	-162
A3	61.6	19.9	90.0	10.0	8.6	5.6	3,713	589	1,220	-163

Source: Authors estimates.

value of output per hectare of irrigated area and groundwater footprints while assuming that there are no deficits of green fodder or dry fodder for feeding the dairy animals.

- A1: Complete elimination of rice area.

Complete elimination of rice area can bring the total CWU of groundwater to well within the natural recharge level, but this also reduces the value of output by 1,370 US$/ha. Although hydrologically attractive, this is not a realistic scenario at the ground level. This scenario over a large area will result in huge final losses and have larger food security implications outside Moga area.

- A2: Partial reduction of rice area to bring groundwater footprints below the natural recharge limits.

If rice occupies 20% less area than at present, the total CWU can be reduced by 162 mcm, bringing total groundwater depletion under the natural recharge limit. However, this scenario also reduces value of output by about 10%.

- A3: Optimize the value of output by decreasing the rice area and increasing the number of cross-bred cattle, while maintaining green and dry fodder surpluses for feed and groundwater footprints below natural recharge limits.

Under the given constraints, value of output is optimized with 8 dairy animals (5 crossbred cows, 3 buffaloes) in milk and another 4 animals not in milk in a 6 ha area. This requires raising green fodder area in *Kharif* season to 20%, reducing rice by 26% from the base scenario. Altogether this scenario has land use intensity 81 and 100% for *Kharif* and *Rabi* seasons, and raises It gives 208 US$/ha more net value of output than the base scenario.

Intensification of dairy farming activities can bring significant hydrological and financial benefits to Moga, while still ensuring substantial surpluses for meeting rice demand outside Moga. An ideal combination under the current levels of crop and milk productivities is: 3 and 5 buffaloes and cross-bred cows in 6 ha land, and 62 and 90% rice and wheat area, 20 and 10% green fodder area in *Kharif* and *Rabi* seasons respectively.

Although these changes will certainly reduce the internal CWU of Moga, it is clear that the total external CWU will also increase. What is not clear from this analysis, however, is how Moga can reduce its external CWU, mainly through import of components of feed concentrates. At present, import of various components of concentrate cattle feed contributes to much of the external CWU of Moga. Some of these imports are from irrigated production areas while others are from rainfed production areas.

Places like Moga are classic cases where the virtual water trade can flourish within India. With significantly high milk productivities, and low internal milk CWU , Moga has a large comparative advantage for diversifying agriculture from rice-wheat production systems with high internal CWU milk-wheat production systems with low internal CWU. Corresponding increase in concentrate and dry fodder within Moga offers significant opportunities for areas outside Moga to improve productivity, increase production and export of animal feed commodities that Moga requires. In fact, much of the imports of components of concentrate feed are crops that require less water, and can be cultivated in rainfed areas. Thus, many rainfed areas can also benefit from this virtual water trade with Moga.

CONCLUSION AND POLICY RECOMMENDATIONS

In Moga, green fodder, rice and wheat occupies more than 99% of the annual cropped area These crops contribute to almost all groundwater CWU, which at present is 166 mcm more than the natural recharge limits. *Decreasing internal groundwater CWU is the only solution for long-term sustainable agricultural production.*

Rice production has the highest internal CWU, and most of this is virtually exported from Moga at present. In fact, the total virtual water content of the production surpluses of milk, wheat and rice is more than the level of natural groundwater recharge. On the other hand, the value of output of milk only or milk-wheat production systems are 11 and 18% more than the net value of output of milk-wheat-rice production system. *Given the differences of value of outputs and groundwater CWU, intensifying dairy production with calculated increase in fodder area and decrease in rice area is the most expedient way for controlling groundwater overexploitation.*

The value of output of wheat-milk production systems per unit irrigated area and unit of CWU is 11 and 38% higher than that of milk-wheat-rice production systems. *Small farmers should be strongly encouraged to take up dairy dominant agriculture patterns. As wheat provides dry-fodder for feed, wheat-milk should be the preferred production system for them. If area is too small for both wheat and fodder production, milk only is the preferred production system, where output per internal water footprint is still higher than the milk-wheat-rice system. Additional care should be taken to introduce crossbred cows with higher milk productivity than at present.*

However shifting to dairy intensive production system requires initial investment on procuring dairy animals, preparing animal shed etc. Yet, increase in net value of output of US$1,686 or 1,038 per 6 hectare of irrigated area per year between milk-wheat-rice production system and milk-wheat or milk only production systems, are an incentive for the farmers for this initial investment. *The government, as well as the private sector, such as Nestle, should come forth with credit facilities for the small farmers to make the changes of agriculture production systems financially feasible.*

At present, virtual groundwater export in milk, wheat and rice itself is higher than the natural groundwater recharge. Given the large differences of internal water footprints of milk, wheat and rice, changes in production and cropping pattern throughout Moga is vital for reducing the internal groundwater CWU. Intensifying dairy production *by introducing at least two times more lactating animal population with 10% more green fodder area is the most economical choice.* However, the rice surplus, which is about 99% of the current production, contributes to food security of the large population outside Moga. *Therefore, only a partial reduction in rice area is preferred among medium and large farmers. Rice area of these farmers should be reduced so that overall rice area can be at most 62% of the net irrigated area to make agriculture in Moga a financially viable and hydrologically sustainable enterprise.*

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