POSSIBLE BREAKTHROUGHS
CONJUNCTIVE WATER USE AND DRAINAGE

Conjunctive water use refers to the simultaneous use of surface water and groundwater to meet crop demand.[1] Besides meeting quantitative water needs, conjunctive use also blends water from various resources to arrive at preferred water quality. Conjunctive use as a management strategy typically allows organizations to address the energy-water nexus in the agricultural sector while raising productivity. Moreover, water logging is estimated to affect 24% of the global irrigated area.[2] This is the result of inadequate irrigation management and insufficient investment in drainage. Conjunctive water use could effectively lower groundwater tables and reduce water logging.

[1]World Bank 2006, [2]FAO 2011b

Description

Conjunctive water use is distinguished by cyclic and mixed (or blended) conjunctive use. Cyclic conjunctive use is the successive application of water from different sources. The cycle can take place within the same cropping season, in between seasons and within the scheme itself. In mixed/blended conjunctive water use, water from various sources is mixed in the canal. A much-debated topic in scientific papers is what type of conjunctive use actually reduces the accumulation of salts in the soil profile and limits yield reduction. Conjunctive water management can be applicable in areas with problems of high salinity or high alkalinity. Highly saline waters are mostly encountered in arid parts (annual rainfall 300-350 mm), whereas groundwater showing a high incidence (30-50%) of residual alkalinity exists in semi-arid parts (annual rainfall 500-700 mm).[3] See table 1 for an overview of the causes of salinity/alkalinity, the applicable conjunctive use methods and the research focus areas.

Table 1
Saline and alkaline soils/water (causes, conjunctive use methods and research focus areas)

Constraint	Cause	Conjunctive use method	Applies to
Saline soil	Poor drainage, constrained freshwater sources, human activities, such as land clearing and aquaculture	Leaching of salts during monsoon or rainy season with subsurface drainage, pre-sowing irrigation with good quality water	Northern and southern coastal provinces of India, Egypt, Bangladesh, Pakistan, China, Iran
Alkaline soil	Natural presence of soil minerals producing sodium carbonate and sodium bicarbonate, poor drainage	Minimizing the precipitation of calcium or maximizing the dissolution of precipitated calcium, using subsurface drainage	China, northern part of India, Central Europe
Saline water	High salinity surface or groundwater caused by salt accumulation and seepage through saline soils, re-use of high salinity drainage water	An efficient substitution of low-salinity water by blending fresh surface water with salty groundwater	Northern and southern coastal provinces of India, Egypt, Bangladesh, Pakistan, China, Iran
Alkaline water	Application of soft water in irrigation (surface or groundwater) containing a relatively high proportion of sodium bicarbonates, industrial polluted waters	Blending and cyclic use of alkali and good quality waters	China, northern part of India, Central Europe

[3]Minhas et al. 2007

Geography

Conjunctive use practices are dominantly found in large-scale irrigation in South Asia, Iran, Pakistan, and the northern and southern coastal provinces of India, Bangladesh and China. A large-scale survey in India, Pakistan, Nepal-Terai and Bangladesh conducted by the International Water Management Institute (IWMI)[4] shows that, for the region as a whole, 55% of the irrigated area is exclusively irrigated by groundwater and 22% is under conjunctive use of ground and surface water.[5] See table 2 for an overview.

Iran

In central Iran, semi-arid regions with low precipitation and high potential of evapotranspiration are abundant. Rapid population growth, increased irrigation and industrial development during the past decades have put increasing pressure on water resources.[6] Upstream of Nekouabad and in the Borkhar area north of Esfahan city, surface water canals have been implemented. These areas were originally developed using only groundwater. However, this was insufficient to meet the demands of the total potentially irrigable area. The irrigation area has now been designed to operate under conjunctive use systems.[7]

Pakistan

In Pakistan, groundwater for irrigation is used both in isolation and in conjunction with canal water. Conjunctive use of surface and groundwater is more common due to two main reasons: 1) to increase the supply of irrigation water and 2) to improve groundwater quality through dilution. However, farmers are not fully aware of mixing ratios, resultant salinities and their long-term consequences on crops and soils.[8] Drainage in Pakistan is done by both surface and tube well (vertical) drainage. Kazmi et al.[9] show that in the Lagar area, within the general picture of conjunctive use of canal water and groundwater, there is a clear spatial pattern between upstream and downstream areas, with upstream areas depending much less on groundwater than downstream areas. This has to do mainly with differential access to canal and tube well water, resulting in different farmer responses in terms of irrigation strategies.

[4]IWMI 2002 in World Bank 2006, [5]Shah et al. 2006, [6]Safavi et al. 2002, [7]Salemi et al. 2000, [8]Qureshi et al. 2004, [9]Kazmi et al. 2012

Bangladesh

In Bangladesh in 1999, of the 3.99 million hectares of irrigated area, approximately 70% of irrigation was dependent on groundwater.[10] However, the advantages of exploiting groundwater irrigation sources are under serious threat due to arsenic contamination. Recent evidence shows that the groundwater sources of 61 out of 64 districts are contaminated with arsenic.[11]

China

In arid and semi-arid areas of northern China, water logging, salinity and alkalinization are considered serious constraints to agricultural development in irrigated land. Saline/alkaline cultivated land in China covers 7.73 million hectares (5.51 million hectares of which have been improved). It was estimated in 1996 that 24.58 million hectares were subject to water logging, of which 20.28 million hectares were equipped with drainage.[12]

India

In India, it is estimated that nearly 8.4 million hectares are affected by soil salinity and alkalinity, of which about 5.5 million hectares are also waterlogged.[13] Due to intensive groundwater use for irrigation in Uttar Pradesh, 50% of the land area now has water tables that are critically low. Impacts are irrigation tube-well dewatering, yield reduction and pump failure. At the same time, canal leakage and flood irrigation in the head water zones have resulted in around 20% of the land area threatened by rising and shallow water tables, with water logged soils and salinization leading to crop losses and even land abandonment.[14]

[10] Mainuddin 2004, [11] Ibid. [12] FAO 2011a, [13] Ritzema et al. 2008, [14] Foster et al. 2010

Table 2
Profile of irrigation by groundwater and surface water sources

Region (1)	Total cultivated land (ha) (2)	% rainfed (3)	Area irrigated as % to cultivated land[i] (4)	% of cultivated area under respective sources of irrigation			
				Pure canal irrigation (5)	Pure groundwater irrigation (6)	Conjunctive use of ground and surface water (7)	Other sources (8)
Northwestern India	27,778	8.1	91.9	2.9	82.8	5.6	0
Eastern India	10,719	55.6	44.4	3.3	24.1	11.0	5.9
Central Indian tribal belt	11,762	58.3	42.3	0.7	26.4	13.3	1.3
Central and Western India	57,913	71.4	28.6	0.6	24.8	2.0	1.2
Interior peninsula India	31,859	77.2	22.8	2.4	13.2	1.8	5.4
Coastal peninsular India	10,503	45.7	59.0	15.8	19.6	14.7	4.3
India	**150,534**	**57.0**	**43.4**	**2.7**	**32.8**	**5.0**	**2.4**
Pakistan Punjab	63,149	56.9	50.5	16.0	5.0	21.9	0
Pakistan Sindh	4,056	52.5	43.1	19.9	7.3	20.3	0
Pakistan NWFP	7,885	49.5	50.4	28.5	6.8	4.7	0
Pakistan	**75,091**	**55.9**	**44.2**	**17.5**	**5.3**	**20.0**	**1.4**
Northwestern Bangladesh	1,544	18.4	81.6	0	79.2	0	1.3
Rest of Bangladesh	4,350	43.9	56.1	0.2	25.8	6.2	23.8
Bangladesh	**5,904**	**37.2**	**62.8**	**0.2**	**39.9**	**4.6**	**17.9**
Nepal Terai	4,452	42.1	62.1	28.3	31.8	0.3	0
Region aggregate	**236,070**	**55.8**	**44.5**	**7.8**	**24.2**	**9.7**	**2.0**
Source contribution to total irrigated area (%)				17.8	54.8	22.0	4.5

Source: Primary survey conducted by IWMI in 2002. [i]The questionnaire asked sample farmers to separately provide figures for their farm areas under rainfed farming and under different sources of irrigation. Columns 3 and 4 are computed based on these; as a result the sum of the % of rainfed and irrigated area does not always add up to 100%. Source: Shah et al. 2006.

Energy

- Groundwater irrigation consumes a large amount of energy:
  - Groundwater irrigation accounts for one-quarter to one-third of national energy demand in India.[15]
  - India, Pakistan, Bangladesh and Nepal pump around 210 km^3 of groundwater every year using some 21 million pumps (13 million electric and 8 million diesel). Total electricity use is 100 billion kWh/year, a market equivalent of US$ 12 billion.[16]
- Falling groundwater tables, due to unsustainable groundwater withdrawal, further increases the energy demand of the agricultural sector:
  - In 2007, tube wells in Punjab consumed 28% of total electricity consumption in the entire state. If groundwater levels continue to fall, tube wells will consume twice as much energy by 2023.[17]
- By compounding groundwater with surface water, energy use in agriculture can be reduced.
  - In the Madhya Ganga Canal Project in Uttar Pradesh, India, conjunctive water use has saved 75.6 million kWh annually (INR 180 million annual cost savings).[18]

[15]Shah et al. 2003, [16]Ibid, [17]NRAA 2009, [18]IWMI 2002 in World Bank 2006

Water

- Conjunctive water use allows for the storing of excess surface water during normal and high rainfall years and the pumping of large volumes of water during drought years.[19]
- Conjunctive water use has reduced conveyance loses in canals by 50%, raised groundwater levels by six meters over a decade and increased the irrigated area 30-fold.[20]
- Conjunctive water management strategies help reduce evaporation losses from reservoirs, as their storage can be drawn down more quickly if groundwater can be relied on to meet water needs later in the year.[21]
- Planned conjunctive use is a smarter and more sophisticated groundwater overdraft water management technique and is being used more and more frequently.[22]
- In arid and semi-arid regions, subsurface drainage systems effectively prevent water logging and root zone salinity in irrigated lands.[23]
- In Egypt, areas with saline soils decreased from 80% (before drainage) to 30% (after drainage) in saline areas and from 40% (before) to 5% (after) in non-saline areas.[24]
- Average groundwater tables decreased from 0.6 m surface before drainage to about 0.9 m surface four years after the installation of subsurface drainage. Most groundwater levels are now under control.[25]

[19]Dudley and Fulton 2006, [20]International Water Management Institute (IWMI) 2002 in World Bank 2006, [21]World Bank 2006, [22]Gleick et al. 2011, [23]Ritzema and Schultz 2010, [24]Ali et al. 2001, [25]Ibid

Productivity

- Conjunctive water management increased farm income by about INR 1,000 and 5,000 per hectare compared to only using canal and tube well water, respectively.[26]
- Paddy yields using the conjunctive irrigation method (3.4, 3.1 and 2.7 t/ha) were on average half a tonne higher than paddy yields solely irrigated with the tank system (2.9, 2.4 and 2.2 t/ha).[27]
- Mixing salt and freshwater:
  - "The profit decreased from 12,000 to 7000 INR/ha when the canal water supply decreased from 15 to 10 cm with a groundwater (EC = 6 dS m_1) use of 15 cm."[28]
- In Uttar Pradesh, India, average cropping intensity can be increased from less than 150% to more than 220% with planned conjunctive use.[29]
- Crop yields increased on average 54% for sugarcane, 64% for cotton, 69% for rice and 136% for wheat. This was mainly because in drained fields groundwater tables and soil salinity levels were 25% and 50% lower than in non-drained fields, respectively.[30]

[26]Jehangir et al. 2003, [27]Sekar 2008, [28]Tyagi 2003, [29]Foster and Garduno 2011 [30]Ritzema et al. 2008

Climate change

- The importance of managing ground and surface water conjunctively increases with water scarcity and with inter- and intra-temporal fluctuations in precipitation, the latter due to climate change.[31]
- Controlled drainage will allow farmers to optimize their on-farm water management based on the specific conditions and their own preferences. Furthermore, it enables farmers to respond to changes in land use and/or the effects of climate change.[32]

Costs and benefits

- Conjunctive water use in the Madhya Ganga Canal Project in Uttar Pradesh, India, increased farmers' income by 26%.[33]
- Farmers in Gujarat, India were attracted to buying land with subsurface drainage at prices five times higher than the pre-drainage period, i.e., for €7,500 to €12,000/ha compared to pre-drainage land values of €1,500 to €2,500/ha.[34]
- Better management of surface and groundwater during the 1996-2004 drought in the Yaqui Valley (Mexico) could have significantly reduced the impact of the drought without affecting profits in wet years.[35]

[31]Gemma and Tsur 2007, [32]Ritzema and Schultz 2010, [33]International Water Management Institute (IWMI) 2002 in World Bank 2006, z`[34]Ritzema et al. 2008, [35]Schoups et al. 2006

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