Groundwater Depletion in Punjab, India

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Abstract

Punjab occupies only 1.57% geographical area of India and is predominantly an agrarian state. About 85% of the state's area is cultivated with cropping intensity of more than 198%. The paddy–wheat crop rotation has led to a manifold increase in irrigation water demand. Unreliable surface water supplies coupled with excessive groundwater pumpage, due to free electricity and agricultural practices, has led to a long-term groundwater decline of 41.6 cm/yr in the state. The state of development and management of groundwater resources has serious implications for the future of agriculture in the state. Some of the policy initiatives taken by the state/central government to combat the problem have been discussed. The results of such initiatives will be visible in the years to come. Apart from various supply and demand side management strategies, the study emphasizes the role of people (participatory approach) for improving the situation.

INTRODUCTION

India is the largest groundwater user in the world with an estimated usage of around 251 km^3/yr.[1] Agricultural demand for irrigation is already the single largest draw on India's water, and estimates by the Ministry of Water Resources indicate that by the year 2050, irrigation needs will rise by 56%. At the same time, India's drinking water demand will double and India will also have to increase water supplies to industries fivefold and supply 16 times more water for energy. While demand for water is increasing, the supplies have been falling. Per capita surface water availability has already slumped from 2309 m^3 in 1991 to 1902 m^3 in 2001 and is projected to fall to 1401 m^3 by 2025 and to 1191 m^3 by 2050.[2]

A State like Punjab, having semiarid climate and highly seasonal monsoon precipitation, contributes 27–40% rice, 55–65% wheat, and 18–25% cotton, with only 1.54% of the total geographical area, to the central pool in the past decades. But this contribution to the nation's central pool comes at the cost of depletion of natural resources. A key regional-scale study using GRACE satellite data, in *Nature*[3] in 2009, showed that 109 km^3 of groundwater has been lost across the states of Punjab, Haryana, and Rajasthan, from 2002 to 2008. This unsustainable deficit poses a grave threat to the continued development of the region and nation. What is more perturbing is that the climatic projections from regional-scale climate modeling indicate increased surface temperatures, increased but highly variable rainfall events. Thus, a great uncertainty lies with regard to the use and impact of groundwater resources.[4]

Groundwater management is the key to combat the emerging problem of water security. Knowledge of groundwater scenario and factors influencing the groundwater augmentation are crucial elements in many hydrological investigations, including agricultural water management.[5] In the alluvial formations, the groundwater levels are expected to have a direct relationship with the evapotranspiration requirements and rainfall. The present topic, therefore, attempts to quantify the impact of rainfall and groundwater draft on long-term groundwater behavior of Punjab State, to ensure better management of this resource.

DESCRIPTION OF THE STATE

Punjab is located in the northwest of India, surrounded by Pakistan on the west, Jammu and Kashmir on the north, Himachal Pradesh on its northeast, and Haryana and Rajasthan on its south. It covers a geographical area of 50,362 km^2 and lies between 29°33′–32°32′N latitudes and 73°55′–76°51′E longitudes, with an average elevation of 300 m above mean sea level (amsl; Fig. 1).

Hydrologically and agro-climatologically, Punjab can be broadly divided into three major zones: northeast, central and southwest zones (Fig. 1).

Northeast zone: It comprises 19% of the geographical area of the state. About 4.5 lakh ha (9% area of the state) of this zone is severely affected by soil and water erosion due to the steep slope (up to 36%) and high rainfall. In this part, the sub-surface aquifers are alluvial in nature and are composed of a heterogeneous complex mass of clays, silts, fine

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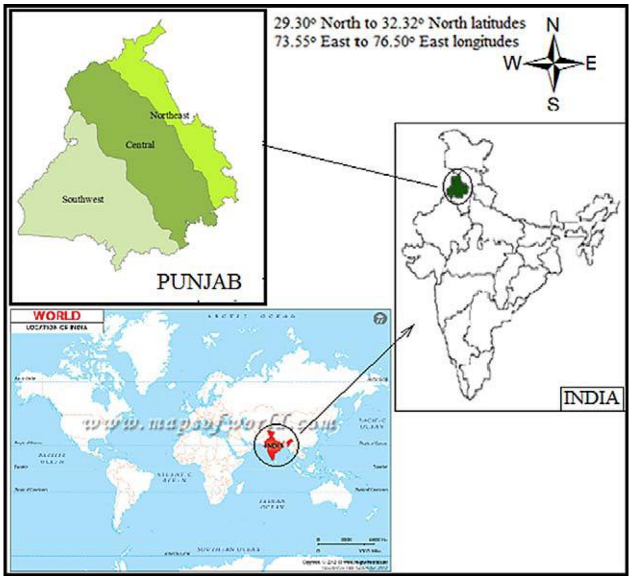

Fig. 1 Location map with agroclimatic zones of Punjab.

sands, coarse sands, and gravels. Hydraulic conductivity varies between 5 m/day and 10 m/day and specific yield between 0.08 and 0.17.[6]

Central zone: It comprises 40% of the geographical area of the State. The groundwater is fit for irrigation and rice–wheat is the main cropping system. The aquifers in this zone are alluvial and are unconfined in nature and capped invariably by a soil crust of 0.60–8.0 m thickness. Hydraulic conductivity varies between 10 m/day and 90 m/day and specific yield between 0.08 and 0.17.[6]

Southwest zone: It comprises 41% of the geographical area of the State. It is popularly known as the cotton belt of the state; 70% of the area is canal irrigated, the groundwater is brackish, and the problem of residual alkalinity is more severe than salinity. The subsurface geological alluvium consists of alternate layers of clay, clay mixed with pebbles and gravels, silt, and sand. The value of hydraulic conductivity varies from 4 m/day to 25 m/day and specific yield from 0.05 to 0.16.[6]

The groundwater flows from northeast to southwest. The hydraulic gradient in the northeast part is steep and ranges from 3.30 m to 5.0 m/km and in the central part it is 0.33 m/km.[7] In southwest region, there is a slow groundwater movement as groundwater elevation contours are widely spaced; however, a steep gradient has been observed around Bathinda which may be due to the low values of lateral hydraulic conductivity and predominant clayey formations.[7]

GROUNDWATER SCENARIO

The average water table depth was 7.32 m in 1998 and 12.79 m in 2012, thus indicating an annual fall of 41.6 cm/yr. Largely though, water levels have declined across the state, but the decline rates have not been uniform, both spatially and temporally. About 2039 ('000 ha) had experienced a fall between 0 m and 3 m and about 1240 ('000 ha) experienced a fall between 3 m and 10 m and 1100 ('000 ha) experienced a fall greater than 10 m in various parts of the State (Table 1). A rise in water table was experienced in 642 ('000 ha), mainly in southwest region besides marginal areas of northeast region of the State. The rise in water levels is attributed to the continuous seepage of water from the network of unlined canals and distributaries and due to the negligible draft from groundwater in the area. The only comfortable areas, where the water level has not lowered much, happened to be in the vicinity of rivers or in those districts where the canals' irrigation network exists for agriculture purposes. The decline rate was observed to be the maximum in the central zone with 50 cm/yr and it is 36 cm/yr in the southwest zone, and 33 cm/yr in the northeast zone (Table 2). A major portion of the central zone registered a fall >10 m, over a span of 14 years (1998–2012). It may also be pointed out that until 2010, the average decline rate in central zone was 72 cm/yr, and due to the above-normal rains in 2011 and 2012, the average decline rate in all three zones had decreased.

Table 1 Proportion of area and the water table depth in different hydrological zones of Punjab.

	Northeast zone			Central zone			Southwest zone		
Year	<3	3–10	>10	<3	3–10	>10	<3	3–10	>10
1998	0	81	19	0	65	35	12	84	4
2004	0	70	30	0	18	82	3	65	32
2010	0	61	39	0	12	88	12	48	40
2011	0	50	50	0	13	87	19	41	40
2012	0	58	42	0	21	79	8	44	48

REASONS FOR DECLINE IN WATER TABLE

This bad situation of the groundwater resources is because of the following reasons:

I. *Shift in cropping pattern and cropping intensity*: The area under paddy cultivation increased from 400 ('000 ha) in 1970–1971 to 2845 ('000 ha) in 2011–2012, which is about 69% of the net sown area. Similarly, the net sown area under wheat increased from 41% (1970–1971) to nearly 44% in 1990–1991, and is presently around 85%. The cropping intensity also increased from 116% in 1970–1971 to more than 191% in 2011–2012. During the 14-year period (1998–2012), there is a 13% increase in the cropping intensity.[8] Also, the net area under irrigation has increased from 70% in 1970–1971 to 98% in 2011–2012. All these combined together have put a tremendous pressure on the water resources.

Table 2 Groundwater draft, rainfall, and rise/fall in mm in different agroclimatic zones.

Year	Northeast			Central			Southwest		
	Rainfall (mm)	Draft (mm)	Change in water table (m)	Rainfall (mm)	Draft (mm)	Change in water table (m)	Rainfall (mm)	Draft (mm)	Change in water table (m)
1998–1999	617	492	0.03	521	794	0.08	300	517	0.24
1999–2000	636	466	−0.54	478	837	−0.85	235	558	−0.59
2000–2001	629	465	−0.42	473	817	−0.80	305	565	−0.55
2001–2002	438	491	−0.38	439	843	−0.64	242	594	−0.62
2002–2003	515	528	−0.75	511	868	−0.86	241	630	−0.65
2003–2004	504	592	−0.15	340	999	0.26	181	701	0.11
2004–2005	788	502	−0.68	526	888	−1.52	268	724	−0.77
2005–2006	668	525	−0.48	579	868	−0.62	338	716	−0.16
2006–2007	897	516	−0.12	689	852	−0.49	412	637	−0.37
2007–2008	906	490	−0.48	592	913	−0.45	316	714	−0.08
2008–2009	740	547	−0.50	571	926	−1.96	244	809	−1.26
2009–2010	582	695	−0.54	442	1091	−0.74	221	914	−1.20
2010–2011	1,008	477	−0.23	724	791	0.57	385	663	1.34
2011–2012	1,008	484	0.69	724	823	0.94	439	682	−0.54
Average	*710*	*519*	*−0.33*	*544*	*879*	*−0.50*	*295*	*673*	*−0.36*

II. *Canal water supplies:* In 1970–1971, the area under canal irrigation was 12.86 lakh ha that rose to 16.6 lakh ha in 1990–1991.[8] However, there has been a significant reduction in canal irrigated area from 1990 to 1991. It fell to 11.13 lakh ha (27%) in 2011–2012 and is highly skewed.

III. *Free/subsidized power*: In Punjab, power for agriculture was totally free from 1997 to 2002 and from 2005 onwards. The power subsidy for agriculture has amounted to Rs. 4778 crores in 2013–2014. Out of the subsidy loss, rice cultivation alone accounts for Rs. 1440 crores (Rs. 14.4 billion) annually.[9]

IV. *Increased tube well density and groundwater draft*: Free or practically free electricity has led to an increase in the number of tube wells, particularly in the central and northern region of Punjab and the use of water was irrational. In 1970–1971, there were 1.92 lakh tube wells, of which 1.01 lakh were running on diesel, and only 91,000 were running on electricity. This number increased to 6 lakh in 1980–1981, touched 8.0 lakh in 1990–1991, and was 13.82 in 2011–2012.[9] The number of electrical tube wells had increased nearly 13 times. The tube well density is already more than 30/km^2 in Barnala, Fatehgarh Sahib, Jalandhar, Kapurthala, Ludhiana, Moga, Nawan Shaher, and Sangrur districts. It ranges from 20/km^2 to 30/km^2 in Amritsar, Bathinda, Faridkot, Gurdaspur, Mansa, Patiala, and Tarn Taran, and is less than 20/km^2 Rupnagar, Ferozepur, and Muktsar districts. Accordingly, there has been a 20% increase in groundwater extraction from 1998 to 2012 (Table 2). In the southwest zone, the percentage increase in groundwater was maximum, i.e., 37%. Here, the availability of groundwater at shallower depth and better availability of canal supplies and shift in cropping pattern from cotton–wheat to rice–wheat for better returns and less risk encouraged farmers for installation of both diesel and centrifugal pumpsets. The corresponding increase in groundwater draft in the northeast and central zones was computed as 15% and 10%. It is pertinent to note that about 70% of total groundwater extraction occurs during monsoon season, inspite of the fact that 80% of the annual rains occur during this season.

V. *Impact of rainfall on water table*: Rainfall is the most significant source of groundwater recharge and hence changes in the rainfall pattern leave distinct imprint on the groundwater regime of an area. On an average, the northeast, central, and southwest zones received 710 mm, 544 mm, and 295 mm of annual rainfall from 1998 to 2012 (Table 2), respectively. There was high variability (41–98%) in the amount of rainfall received in different zones and years during the monsoon season, compared to the annual rainfall, but overall one can conclude that about 68% of the total rains occur in the monsoon period. The post-monsoon water levels indicate the impact of monsoon rainfall and recharge due to irrigation on groundwater levels (Fig. 2). It was observed that there was an average groundwater rise of 77 cm and 29 cm in northeast and central zones, whereas southwest zone experiences a marginal fall of 4-cm post monsoons. Monsoon rainfall of more than 650 mm in the northeast region resulted in more rise in water table depth in the central zone. In the southwest zone, the post-monsoon water level dropped in almost

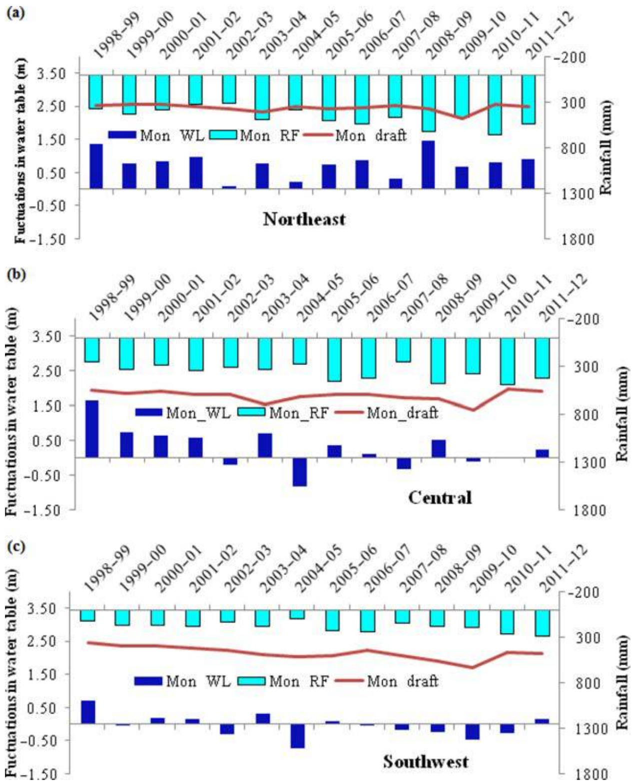

Fig. 2 Rainfall, groundwater draft, and change in water table in different zones during monsoon period.

all years except when the region received a monsoon rainfall of more than 200 mm. However, the effect of rainfall appeared to be delayed/reduced when the water table lowers beyond 10 m or when the preceding year rainfall was less. It was also concluded that post-monsoon increase in water levels is dependent on the spatial variability and the amount of rainfall. But, by the end of non-monsoon period (October to June), fall of 108 cm, 75 cm, and 31 cm in groundwater levels was computed in the northeast, central, and southwest zones, respectively. This points to the fact that subsurface flow is rapid in northeast zone due to the high hydraulic gradient in this zone. The direction of groundwater flow is from northeast to southwest and any water harvesting activity done in the foothills area will add to the groundwater reservoirs in the central zone. Therefore, studies on the basis of demarcation of aquifer boundaries are extremely necessary for sustainable conservation of groundwater.

CONSEQUENCES OF GROUNDWATER OVEREXPLOITATION

In sustaining agricultural production and food security, Punjab has already overused and depleted its good quality groundwater resources. The increasing dependence on groundwater resources has led to widespread decline in water table in the central Punjab, high investment into tube wells, increased operation and maintenance cost, more power consumption, and deterioration of groundwater quality. The replacement costs from centrifugal to submersible pumps for about one million tube wells alone work out to be Rs. 97.56 billion at the rate of Rs. 80,000 each. Groundwater depletion has also increased the energy demand in the State. Statistics reveals that electrical consumption in agricultural sector has increased from 463.4 million kWh to 10,248.6 million kWh during 1970 to 2012.[8] Also, the ratio of annual groundwater draft to unit energy consumed for 2004 and 2009 yield values of 5.19 m^3/kWh and 3.85 m^3/kWh, respectively.[10] Added to this, the policy of free electricity to farmers has resulted in a huge burden on the State exchequer. It may be noted that the subsidy had increased by 3.62 times more in 2000–2001 as compared to the years 1996–1997, and in 2010–2011, this has risen up by 3.44 times more as compared to the years 2005–2006. The World Watch Institute has warned that if water is hauled at this rate, groundwater in Punjab shall be over by 2025.

POLICY INITIATIVES

The Central/State Government is not in favor of groundwater legislation as it apprehends that such a step will cause hardship to farmers. However, to tackle groundwater overexploitation, the government has taken the following initiatives:

I. The Punjab Preservation of Subsoil Water Act, 2009, prohibits farmers from sowing nursery of paddy before 10th May and transplanting paddy before 10th June in a year. The main purpose of the Act is to save groundwater by prohibiting sowing and transplanting paddy before specified dates in hot and dry periods. With the successful implementation of this Act, it is estimated that 276 million units of electricity can be saved and the fall in water table can be checked by about 30 cm.[10]
II. Crop diversification program same separator as in IV. Under this, Punjab plans to reduce area under paddy from 28 lakh ha to 16 lakh ha in a phased manner over a period of six years. It has proposed to shift this area to maize (4 lakh ha), cotton (2 lakh ha), sugarcane (1.5 lakh ha), fodder (1.5 lakh ha), agro Forestry (2 lakh ha), pulses, and fruits and vegetables (1 lakh ha).[11]
III. The Central Ground Water Board (CGWB) has proposed new schemes on artificial recharge and aquifer mapping and management under the Twelfth Five-Year Plan period.[12,13] In this, about 79,924 structures in rural and 375,000 in urban areas are proposed for the Punjab State. It is estimated that influence of recharge scheme will be observed about 26,650 km^2 area and it will help to check decline in water level. The aquifer mapping will help to assess future prospects for the groundwater resource, particularly with regard to the extent and thickness of

aquifers and characteristics such as transmissivity, storativity, and groundwater quality.

IV. Micro irrigation—promotion of drip and sprinkler and polyhouse technology to conserve water. Various subsidies are being provided by the State and Central Government for promotion of this technology.

V. The State Government is providing 50% subsidy to individual farmers for laying of RCC Underground Pipe Line System to propagate on-farm water conservation by replacing low-efficiency kutcha field irrigation channels owned by them in all districts of the State.

CONCLUSIONS

Understanding groundwater overexploitation/use is complex and very much influenced by numerous factors. The state of development and management of groundwater resources in Punjab is a matter of concern for the future of agriculture in the state. One of the biggest reasons for the groundwater depletion trends across the region has been attributed to high irrigation requirement, which is dependent on the cropping pattern and rainfall. In addition to this, subsidized or free power is responsible for the rapid depletion and overexploitation of groundwater resources. There is an urgent need to check the decline in water table in the central zone by reducing the groundwater demand or increasing the groundwater supplies. The groundwater demand can be reduced by adopting efficient irrigation practices/technologies, i.e., micro irrigation, bed planting, laser leveling zero tillage, crop diversification, and others.[14] The groundwater potential can be increased by constructing various types of checking structures across the vast (3400 km) network existing but defunct drains,[15] renovating village ponds to increase their recharging capacity,[16] and maintaining the recommended height of bunds in paddy fields to store maximum rain water.[17] The policy makers have already made some efforts to prevent further depletion of this resource, like delayed paddy transplanting; implementation of various artificial groundwater recharge schemes; promoting crop diversification of low water-consuming crops such as maize, cotton, sugarcane, fodder, and agro-forestry; and providing training and subsidies for promoting drip, sprinkler, and polyhouse technology. All these activities need to be adopted in the right spirit and in holistic manner for tangible results. Also, there is a need to strengthen more people participatory projects to create public awareness regarding the natural resource degradation and its management.

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