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Assessment of Groundwater Extraction and Water Footprints In Punjab

Navdeep Kaur and Vipan Kumar Rampal[1]

Department of Extension Education, Punjab Agricultural University, Ludhiana-141 004, India
[1]Krishi Vigyan Kendra, Fatehgarh Sahib-140 406, India
E-mail: kaur2949@gmail.com

Abstract: This study investigates regional disparities in groundwater extraction and irrigation practices across Punjab. A total of 500 farmers from 20 villages were surveyed, with data collected on borewell depth, water levels, motor capacity, and water productivity. In central Punjab districts i.e. Sangrur, farmers heavily rely on deep submersible pumps and long-duration crop varieties. Sangrur exhibits the deepest borewells (355 ft) and highest motor capacities (19.22 hp), reflecting severe groundwater extraction. Conversely, southwestern districts such as Bathinda and Fazilka use centrifugal pumps and benefit from canal water to address groundwater scarcity and quality concerns. Water footprints vary significantly, with Bathinda and Sangrur exhibiting the highest for paddy (2366 and 2245 l/kg respectively). Sangrur shows a high footprint for Basmati rice (3357 l/kg) and Bathinda exhibits highest for wheat (760 l/kg). Water productivity varies across districts, higher productivity observed for paddy in Hoshiarpur (0.605 kg/m^3) and Rupnagar (0.541 kg/m^3). For wheat, water productivity was higher in Sangrur (1.658 kg/m^3), Hoshiarpur (1.603 kg/m^3), and Rupnagar (1.597 kg/m^3). The study emphasizes the urgent need for region-specific water management strategies, including promoting short-duration crops, enhancing canal infrastructure, and implementing artificial groundwater recharge.

Keywords: Groundwater, Water footprint, Tubewell, Water productivity

Freshwater is essential for agriculture, but its availability is increasingly under pressure due to the rising population, urbanization, and growing irrigation demands. While 75% of Earth's surface is covered by water, only 2.7% of it is freshwater. The world's population depends on just 0.75% of the total global water resources. Although freshwater resources are renewable, their availability is limited both geographically and temporally. India holds only 4% of the world's freshwater, with 85% of it being used in agriculture (Dhawan 2017). Punjab has a total of 50.36 lac hectares geographical area and 83 per cent area under cultivation and cropping intensity about 191.7 percent. Before independence, Punjab was known as the "Land of Five Rivers" due to the Sutlej, Beas, Ravi, Chenab, and Jhelum rivers. Post-independence, only the Sutlej, Ravi, and Beas flow through the region. Significant investments were made in irrigation infrastructure, including the construction of dams and reservoirs, along with the expansion and remodeling of the canal network in Punjab. The construction of multipurpose storage dams on Punjab's major rivers has greatly improved water regulation and helped distribute water more evenly throughout the year (Jairath 1985). Punjab has twelve major canals serving both households and agriculture. However, poor management and uneven distribution of canal water have left many farmers dependent on groundwater for irrigation. In Punjab, 99.8% of the cultivated area is irrigated, making it one of the few regions where agricultural productivity is less affected by drought due to its complete reliance on groundwater irrigation. As the demand for irrigation water increases, driven by the country's food security needs, pressure on groundwater resources has intensified, leading to drastic depletion. Punjab now has about 1.53 million tube wells, contributing to the expansion of the net irrigated area (GOP 2023). The state's net annual groundwater availability is 13.83 million acre-feet (MAF), but current extraction is 22.70 MAF, with 21.62 MAF used for irrigation. This represents an over-extraction rate of 164%, leading to a continuous decline in the groundwater table (CGWB 2022).

Once renowned for its abundant water resources, Punjab is now on the brink of a severe water crisis, driven by unsustainable over-reliance on groundwater for irrigation. The state's groundwater reserves are being depleted at an alarming rate, threatening the future of agriculture and water security. This study was planned to shed light on the critical groundwater extraction crisis in Punjab through scientific assessment of groundwater extraction in various crops.

MATERIAL AND METHODS

The study was conducted in five districts of Punjab i.e. Bathinda, Sangrur, Fazilka, Rupnagar, and Hoshiarpur selected from three agro-climatic zones based on the highest acreage of five major crops such as rice, wheat, cotton, maize, and sugarcane during 2019-20. Using a multi-stage sampling method, two blocks from each district and two villages from each block were randomly chosen, resulting in a total of 20 villages. From each village, 25 respondents were selected at random, leading to a total sample size of 500 farmers.

Groundwater extraction: Groundwater extraction was analyzed by gathering information on bore well depth, water level, and motor capacity used by the respondents for crop cultivation.

Water inputs based water footprint (WFP): This referred to the total volume of irrigation water applied by a farmer to produce a crop.

$$WFP_{water\ input} = \frac{\text{Irrigation water applied for } i^{th} \text{ crop per unit area}}{\text{Yield of } i^{th} \text{ crop per unit area}}$$

Water productivity: Water productivity was calculated as the inverse of the WFP.

RESULTS AND DISCUSSION

Sources of irrigation water: This study indicates significant regional disparities in water use practices, groundwater levels, and the associated irrigation infrastructure, reflecting the complex interplay between natural resource availability and agricultural demands. The study reveals that farmers across Punjab primarily depend on groundwater, with the type of borewell varying by region (Table 1).

In Sangrur, Hoshiarpur, and Rupnagar districts, farmers overwhelmingly utilize submersible pumps due to their deeper water tables and limited access to canal water. Conversely, in the southwestern districts of Bathinda and Fazilka traditionally known as the cotton belt, farmers employ centrifugal pumps alongside canal water to offset the scarcity and poor quality of groundwater. The reliance on submersible pumps in central Punjab districts like Sangrur can be attributed to the declining availability of surface water and the inefficiency of canal infrastructure. In contrast, the use of centrifugal pumps in Bathinda and Fazilka indicates a dual dependence on both groundwater and canal water, reflecting

Table 1. Distribution of respondents according to the source of irrigation water (Percent)

District	Groundwater		Surface water/ Canal water
	Bore well		
	Submersible	Centrifugal	
Sangrur (n=100)	100	-	15
Hoshiarpur (n=100)	100	-	-
Rupnagar (n=100)	100	-	-
Fazilka (n=100)	40	42	100
Bathinda (n=100)	72	14	100

regional efforts to manage irrigation needs amidst fluctuating water quality and availability.

Groundwater extraction: Groundwater extraction has been assessed on the basis of water level (Table 2) and bore depth (Table 3). In Fazilka district, the water table is relatively shallow, ranging from 21 to 60 feet for most respondents. However, due to its location at the tail end of canal channels, farmers in Fazilka face periodic water shortages, especially during peak cropping seasons. In Bathinda, 45% of fields have water levels between 61 and 100 feet, while 63% of fields in Fazilka report water levels between 21 and 60 feet.

The shallower water tables in Fazilka contrast with the deeper tables found in other districts, emphasizing regional differences in aquifer characteristics and groundwater recharge rates. Sangrur and Hoshiarpur districts exhibit deeper water tables, with Sangrur predominantly between 141 and 180 feet and Hoshiarpur showing similar depths for about 50% of respondents. The deeper water levels in Sangrur reflect the district's heavy reliance on groundwater, exacerbated by poorly maintained canal infrastructure that fails to provide consistent surface water access. The declining water tables in Sangrur and similar districts highlight unsustainable extraction rates driven by intensive agricultural practices and ineffective surface water management. In Rupnagar, a significant proportion of respondents (69%) report water levels between 101 and 140 feet, suggesting a moderate groundwater depth compared to other districts. The relatively higher water table in Rupnagar can be partially attributed to its location and rainfall patterns, which aid groundwater recharge. Sangrur district facing severe groundwater depletion with 64.85% of bore wells extending beyond 300 feet, highlighting a considerable reliance on deeper groundwater (Table 3). This trend raises concerns about sustainable extraction rates and the potential for further depletion of the water table.

In Fazilka, nearly 49% of bore wells are less than 100 feet deep, indicating a reliance on accessible groundwater despite challenges like periodic canal water shortages and but this does not imply ample water availability. This points to the regional limitation where quality water is accessible only at certain depths, beyond which extraction becomes unfeasible. In contrast, Bathinda shows over 80% of bore wells situated between 100-200 feet, reflecting dependence on groundwater due to limited surface water during peak cropping seasons. Similarly, Hoshiarpur and Rupnagar report 40.21 and 76.44% of bore wells, respectively, in this depth category. The presence of bore wells beyond 400 feet in Sangrur (15.15%) and Bathinda (15.54%) emphasizes the risks of deep extraction on local ecosystems. Overall, the varying bore well depths across these districts reflect different groundwater management strategies, underscoring the urgent need for sustainable practices to address groundwater depletion and ensure agricultural viability in Punjab. Despite the presence of surface water, the preference for water-intensive paddy cultivation has intensified the pressure on groundwater resources, exacerbating the region's growing water crisis.

In Rupnagar district, with the highest number of electric motors (225), predominantly in the 12.5-15 hp range, farmers employ significant power to extract groundwater. In Sangrur district, the higher motor capacities (17.5-20 hp) align with the deeper water tables, reflecting the energy-intensive nature of groundwater extraction in this region. Conversely, in Fazilka and Bathinda districts, motor capacities are generally lower (5-10 hp), corresponding with the shallower water tables and partial reliance on canal water. This lower capacity highlights the supplementary role of canal water in these districts' irrigation practices.

Water footprint and water productivity of crops: There are significant variations in bore depth, water levels, and electric motor capacities across districts, reflecting differences in groundwater availability and extraction needs. Sangrur district recorded the deepest bore depth (355 ft), with a water level of about 160 ft, and the highest motor capacity (19.22 hp), indicating greater extraction challenges. The primary reason for this is the extensive area under rice cultivation and the widespread adoption of the long-duration variety PUSA 44, which has led to significant groundwater exploitation in the district (Kaur 2021). PUSA 44 requires higher water input due to its longer crop duration (Singh et al 2022). As a result, Sangrur's heavy reliance on groundwater and the cultivation of long-duration varieties also contributed to the highest water footprint for Basmati rice (3357 l/kg). In contrast, Fazilka district had the shallowest bore (94.78 ft), with a water level of about 28 ft, and the lowest motor capacity (5.53 hp).

Water footprints (WFP) also varied across crops, with Bathinda district showing the highest water footprint for both paddy (2366 l/kg) and wheat (760 l/kg), likely due to its dry conditions requiring more irrigation. The water footprint for

Table 2. Percent distribution of the respondents on the basis of water level at field in different districts

Water level (ft)	Sangrur (n=100)	Hoshiarpur (n=100)	Rupnagar (n=100)	Fazilka (n=100)	Bathinda (n=100)
0-20	-	-	-	33	24
21-60	-	30	-	63	22
61-100	-	20	31	3	45
101-140	2	-	69	1	6
141-180	98	50	-	-	3

Table 3. Percent distribution of the bore well on the basis of bore depth in different districts

Bore depth (ft)	Sangrur	Hoshiarpur	Rupnagar	Fazilka	Bathinda
<100	-	-	-	48.94	-
100-200	-	40.21	76.44	51.06	80.31
200-300	20.00	27.51	23.56	-	1.55
300-400	64.85	32.28	-	-	2.59
400-500	15.15	-	-	-	7.77
500-600	-	-	-	-	5.70
>600	-	-	-	-	2.07

Table 4. Distribution of the electric motors per 100 farmers on the basis of different capacityin different districts

Motor capacity (hp)	Sangrur	Hoshiarpur	Rupnagar	Fazilka	Bathinda
3-5	-	-	-	9	-
5-10	-	181	90	93	127
12.5-15	33	4	133	-	50
17.5-20	119	-	2	-	-
25-30	15	-	-	-	2
Total	167	185	225	102	179

*Multiple Responses

Table 5. Average groundwater extraction and water use for the cultivation of crops

Districts	Bore depth (ft)	Water level (ft)	Electric motor capacity (hp)	Water productivity (kg/m^3)			Water footprints (l/kg)		
				Paddy	Basmati	Wheat	Paddy	Basmati	Wheat
Sangrur	355.00	159.65	19.22	0.445	0.298	1.658	2245	3357	603
Hoshiarpur	248.18	103.80	9.11	0.605	_	1.603	1652	_	624
Rupnagar	187.23	112.28	10.82	0.541	0.438	1.597	1849	2282	626
Fazilka	94.78	28.29	5.53	0.487	0.435	1.377	2052	2299	726
Bathinda	206.69	58.97	9.83	0.423	0.429	1.316	2366	2329	760

paddy in Sangrur district (2245 l/kg) was nearly on par with that of Bathinda (2366 l/kg). Conversely, districts like Hoshiarpur and Rupnagar, which receive higher rainfall and have loamy soils, had lower water footprints—1652 l/kg and 1849 l/kg, respectively. Similarly, water productivity varies across districts, with higher productivity observed for paddy in Hoshiarpur (0.605 kg/m^3) and Rupnagar (0.541 kg/m^3). For wheat, water productivity was higher in Sangrur (1.658 kg/m^3), Hoshiarpur (1.603 kg/m^3), and Rupnagar (1.597 kg/m^3), due to differences in soil types and weather conditions

CONCLUSIONS

This study highlights the critical state of groundwater resources in Punjab, particularly in districts like Sangrur, where borewells extend beyond 300 feet and water levels are as deep as 180 feet, reflecting excessive reliance on deep groundwater extraction. There was significant disparities in bore depths, water levels, and motor capacities across districts, with Sangrur exhibiting the highest motor capacities (up to 19.22 hp) to meet the demands of groundwater extraction for high-water-use crops. In contrast, districts like Fazilka, with shallower water tables and lower motor capacities (5.53 hp), partially offset their irrigation needs with canal water. Water productivity and water footprint data suggest significant variation across districts, with Sangrur and Bathinda recording the highest water footprints for paddy and wheat. Rupnagar and Hoshiarpur districts, with higher rainfall and more efficient water use practices, demonstrate better water productivity. The results underline the importance of region-specific water management strategies that promote efficient irrigation and encourage crop diversification to reduce pressure on groundwater resources. Implementing improved irrigation practices, optimizing water use in agriculture, and enhancing surface water management are essential steps to ensure the long-term sustainability of Punjab's water resources and agricultural viability.

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