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Groundwater use and sustainability in Punjab agriculture: insights from a field survey

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Abstract Paddy is a water-intensive crop, and its cultivation is the prime cause of the depletion of groundwater resources in Punjab. We survey paddy farmers' crop choices, water use, and opinions on the causes of the depletion of groundwater resources. To make long-term groundwater use sustainable, farmers can adopt water saving technologies and practices and diversify crops. But adoption is abysmal, and diversification into alternative crops entails high production and marketing risks. To improve adoption, the government must promote water saving technologies and practices. And assured marketing at remunerative prices is a prerequisite for crop diversification.

Keywords Groundwater sustainability, water-saving technologies, crop diversification, Punjab agriculture

JEL codes Q15, Q16, Q25, Q32, Q56

India is the top user of groundwater in the world. The country consumes more than 25% of the freshwater in the world and uses 88% of it for irrigation. Much of its agricultural production depends on the excessive use of water, and productive regions are likely to experience water scarcity in the long run. Already, about 60% of the country's aquifers are under severe stress (World Bank 2012), and the water table in the Indus basin is the second-most overstressed in the world (Gorton 2017). The over-dependence and over-exploitation is particularly severe in the northwest of India, or the green revolution belt.

The term "green revolution" refers to the policies instituted since the late 1960s that transformed India from being a food-deficit country into a food self-sufficient and food-surplus country (Rena 2004). High-yielding varieties (HYV) of wheat were introduced into Punjab in the late 1960s and HYV of paddy in the early 1970s. Access to irrigation was improved; it facilitated cultivation in almost the entire state, and agricultural

growth for nearly two decades (1960s–1980s), and contributed immensely to national food security.

During the 1990s, however, production and productivity fell. Profits fell because production cost rose, investment in agriculture declined, and access to credit was limited (Amanullah et al. 2020; Bera 2015; Narayanmoorthy 2017). To retain their former productivity and profitability, paddy farmers resort to unpropitious use of farm inputs and excessive irrigation.

Paddy consumes three to five times the water required by any other crop (Goud 2015). The continual increase in the area under paddy, the total cultivated area, and the cropping intensity have fuelled the demand for irrigation water. Groundwater irrigates 71% of the state; it has over 1.4 million of the 2.6 million tube-wells in India. And the over-use and over-exploitation of groundwater resources have led the water table to fall faster since the 1990s, threatening long-term

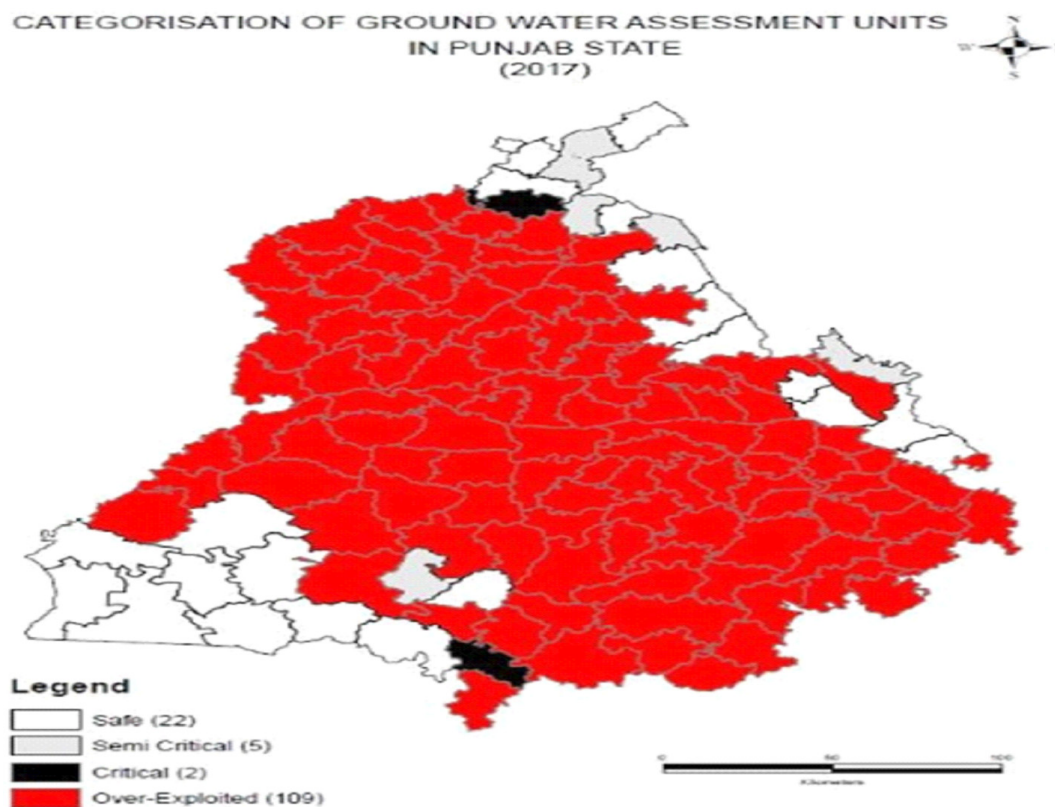


Figure 1 Groundwater use in Punjab

Source <https://irrigation.punjab.gov.in> as cited on 3 March 2020

sustainability (Pandey 2016; Kaur and Vatta 2015). Of the 138 blocks in Punjab, 109 blocks are termed over-exploited and two blocks critical in terms of groundwater use (Figure 1). The water table in about two-thirds of Punjab is projected to fall below 20 m by 2023 and below 30 m in the remaining (Sidhu, Vatta, and Dhaliwal 2010). The problem is worse in the central zone because most of it (3.16 million ha) is under the paddy–wheat system.

Rapid industrialization and urbanization add to the stress (Dhania and Rani 2014). And many existing policies are groundwater-unfriendly. The state provides electricity to farmers free of charge, and they use groundwater excessively and unsustainably. In the “free for all” approach that has emerged, the dwindling groundwater is mismanaged (Shah et al. 2000), and the long-term sustainability of the production system is in doubt.

We survey farmers in Punjab on their cropping choices and pattern of water use, and on their perspective on the over-exploitation of groundwater, its long-term

sustainability, and the fall of the water table. This paper presents the results of the survey and attempts to chalk out pathways for making water use in Punjab agriculture sustainable.

Data

In 2019, a primary survey of 600 farmers was conducted as a part of the Flagship Project 4 (FP4) “Water Use and Management in a Changing Monsoon Climate” being carried out under the project “Transforming India’s Green Revolution by Research and Empowerment for Sustainable food Supplies” (TIGR²ESS). This study is based on that survey.

The primary survey was conducted in central Punjab—where the over-exploitation of groundwater is the highest and the fall in the water table the most severe—in the districts of Amritsar, Jalandhar, and Ludhiana. Two blocks were selected from each district, and 2 villages or village clusters from each block, making a total of 12 villages/village clusters (Figure 2). From each selected village/village cluster, 50 farmers were

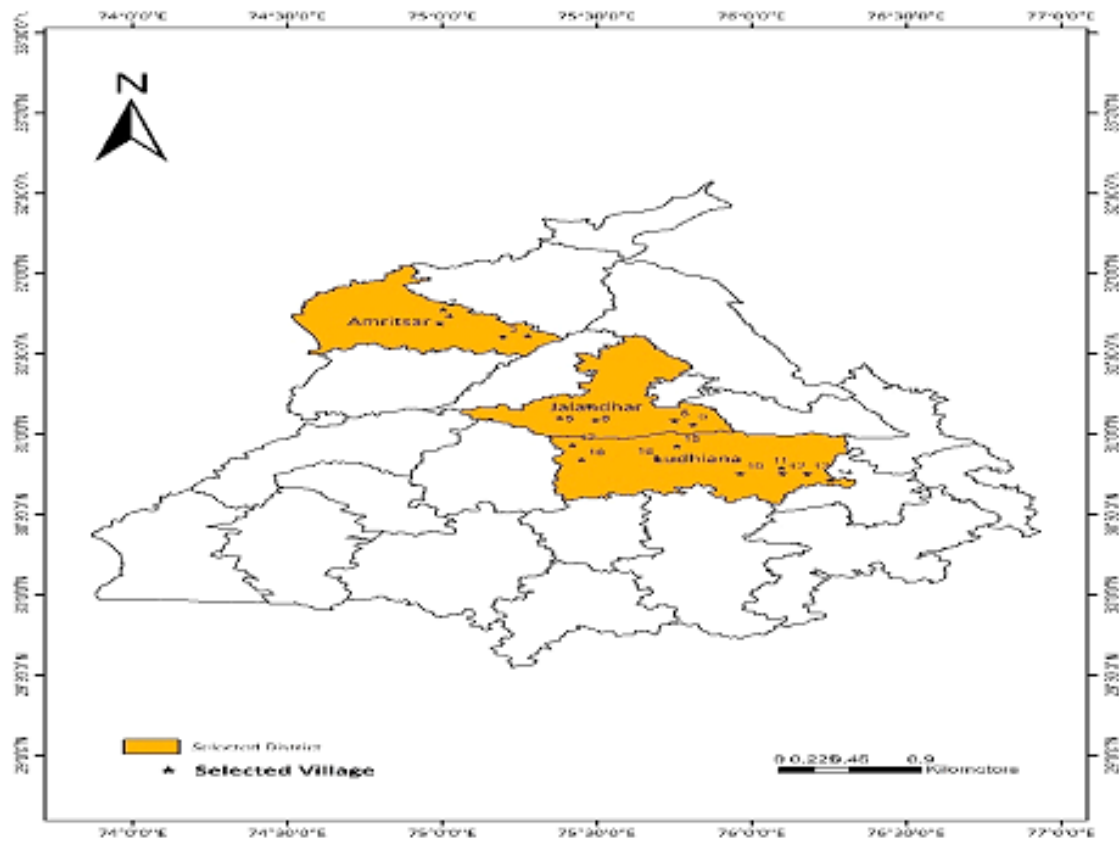


Figure 2 Districts and villages selected for the study

Table 1 Size of the operational landholdings (ha)

Particular	Amritsar	Jalandhar	Ludhiana	Overall
Owned land	2.0 (58.9)	2.0 (29.9)	2.7 (35.1)	2.2 (37.3)
Leased-in land	1.3 (38.2)	4.7 (70.1)	5.0 (64.9)	3.7 (62.7)
Leased-out land	0.1 (2.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Operational land	3.4 (100.0)	6.7 (100.0)	7.7 (100.0)	5.9 (100)

Note Figures in parentheses are % of the operational landholding

selected, making up a total sample of 600 farm households.

By landholding size, marginal farm households (up to 1 hectare (ha)) make up 18% of the sample, small farm households (1–2 ha) 20%, semi-medium farm households (2–6 ha) 35%, medium farm households

(6–10 ha) 12%, and large farm households (more than 10 ha) 15%. The operational landholding size averaged 5.9 ha (Table 1).

Farmers lease in land to increase their operational holdings. About 63% (3.7 ha) of the total operational land was leased in and less than 1% leased out. In

Table 2 Source of irrigation

Source of irrigation	Amritsar (%)	Jalandhar (%)	Ludhiana (%)	Overall (%)
Canal	1.4	0.6	2.9	1.7
Tube well	84.1	95.2	85.8	88.3
Both	14.5	4.1	11.3	10.0
% farmers having access to canal water	19.5	2.0	18.5	14.7

Punjab, the land lease market is very active; and its activity is positively associated with outmigration (Singh, Garg, and Singh 2004). Most of the land is leased out by landowners living abroad or outside the village or by residents who have left farming. Ludhiana and Jalandhar have the largest number of emigrants (Jagat 2019); and about 59% of the land in Amritsar, and about 65–70% in Jalandhar and Ludhiana, is leased in.

Access to irrigation, paddy cultivation, and the fall in the groundwater table

Almost the entire cultivated area in Punjab is under assured irrigation; its primary source is groundwater pumped from tube wells. Tube wells (groundwater) irrigated 88.3% of the operational holdings and canal water only 1.69% (Table 2). In combination, tube wells and canals irrigated almost 10% of the operational holdings in the area.

Despite minor variations in the source of irrigation across the three districts, 14.7% of farmers had access to canal water for irrigation on average, 19.5% in Amritsar, 2.0% in Jalandhar, and 18.5% in Ludhiana. About 53% were situated at the head, 46% were located at the tail, and 25% noted that the canal water was insufficient for irrigation. The problem was more severe among the farmers located at the tail end of the canal.

Most tube wells are submersible (96%). On average, they have 10–15 horsepower (hp), and they are estimated to be irrigating 2.5 ha of land. Over 90% of the tube wells have 5–15 hp, 48.2% had 10–15 hp, and more than 8% had more than 15 hp. More than 40% of the landholdings reported borewell depth of 60–75 metres. About 1.3% of the landholdings had borewell depth that exceeded 120 metres. Nonetheless, almost all farmers in the region reported sufficient access to water for irrigation.

As the water table falls, farmers need to shift from using shallow centrifugal pumps to investing in and using submersible pumps (Fishman et al. 2011; Pandey 2016). The capital investment is compulsory, and it adds to the debt burden of the already debt-ridden farmers.

Water management mitigates the differential access to water that could come about through canal irrigation. Farmers in all three districts have almost equal access to water. For farmers that received insufficient canal water, access to groundwater sources met the deficit.

Assured irrigation is another critical reason for the decline in crop diversity and the increase in the dominance of the paddy-wheat cropping system in Punjab. Paddy and wheat crops, including basmati rice, occupied 75% of the total cropped area (Table 3), potato 6.9%, maize 1.5%, and sugarcane 0.6%. Fodder occupied only around 5% of the total cropped area. All other crops were grown on a negligible area.

Our survey confirms that the water table is over-exploited in most of Punjab's development blocks where the groundwater is fit for irrigation. And it fell in all three districts during the past three decades. Jalandhar witnessed the largest fall.

Farmers' opinions on the depletion of groundwater resources

About 64.7% of the farmers felt that the groundwater resources were being depleted primarily because the area under paddy cultivation was increasing (Table 4), 24% blamed the wasteful use of irrigation water in agriculture, and 11% believed that climate change and the increase in industrial activity is responsible. The perception varied by district: most farmers in Ludhiana blamed the inefficient use of water; in Amritsar and Jalandhar, most farmers blamed paddy. The opinions did not differ considerably by class. A larger proportion

Table 3 Cropping pattern (ha)

Crops	Amritsar	Jalandhar	Ludhiana
Kharif season			
Paddy	0.68 (8.63)	5.46 (40.93)	6.80 (37.20)
Basmati	2.42 (30.71)	0.13 (0.97)	0.34 (1.84)
Maize	-	0.41 (3.07)	0.18 (1.00)
Sugarcane	-	0.25 (1.87)	-
Fodder	0.21 (2.66)	0.41 (3.07)	0.33 (1.79)
Others	0.08 (1.02)	0.01 (0.07)	0.06 (0.31)
Rabi season			
Wheat	3.10 (39.34)	5.34 (40.03)	5.40 (29.54)
Potato	-	0.78 (5.85)	1.96 (10.73)
Mustard	0.04 (0.51)	-	-
Fodder	0.19 (2.41)	0.36 (2.70)	0.32 (1.77)
Others	-	0.19 (1.42)	0.02 (0.09)
Zaid season			
Fodder	0.02 (0.26)	-	0.20 (1.11)
Others	1.14 (14.46)	-	2.67 (14.63)

Note Figures in parentheses are percentages of the total cropped area

of marginal farmers than any other type blamed the depletion of groundwater resources on paddy (Table 5).

Despite all its ills, especially the depletion of groundwater, paddy is popular among farmers. The area under paddy cultivation grew from 0.3 million ha in 1970–71 to almost 3 million ha in 2018–19 (GoP 2019; Kumar and Sangeet 2019; Bhatt et al. 2016). The literature shows that the growth has occurred because the government guarantees farmers procurement at remunerative prices, assures irrigation, and provides free electricity (GoP 2019; Kumar and Sangeet 2019; Bhatt et al. 2016). But more than 95% of the respondents in this study, across all districts and farm sizes, said that the assured prices for paddy are the only dominant factor. Therefore, policy interventions and state- and national-level efforts are required to recommend crops for diversification, assure procurement at remunerative prices, and establish the processing industry.

To make groundwater use in Punjab efficient and sustainable, the literature emphasizes supply-side measures such as rainwater harvesting (Vatta et al. 2018; Taneja, Rawat, and Vatta 2018; Rahman et al. 2014) and demand-side measures such as agricultural practices like crop diversification and water management and water-efficient technologies (Menon 2007; Dixit et al. 2017; Vatta and Taneja 2018). We surveyed the farmers to identify their opinions and priorities.

Table 4 Farmers' opinions on the reasons for the decline in the water table (%)

Reasons for fall in water table	Amritsar	Jalandhar	Ludhiana	Overall
Increase in area under paddy	76.0	98.0	20.0	64.7
Wasteful use for agriculture	14.5	0.5	56.5	23.8
Others	9.5	1.5	23.5	11.5
Total	100.0	100.0	100.0	100.0

Table 5 Farmers' opinions on the reasons for the decline in the water table (by farm size, %)

Reasons for fall in water table	Marginal	Small	Semi-medium	Medium	Large
Increase in area under paddy	91.7	62.4	51.7	64.0	65.6
Wasteful use for agriculture	4.6	18.8	35.9	24.0	25.6
Others	3.7	18.8	12.4	12.0	8.9
Total	100.0	100.0	100.0	100.0	100.0

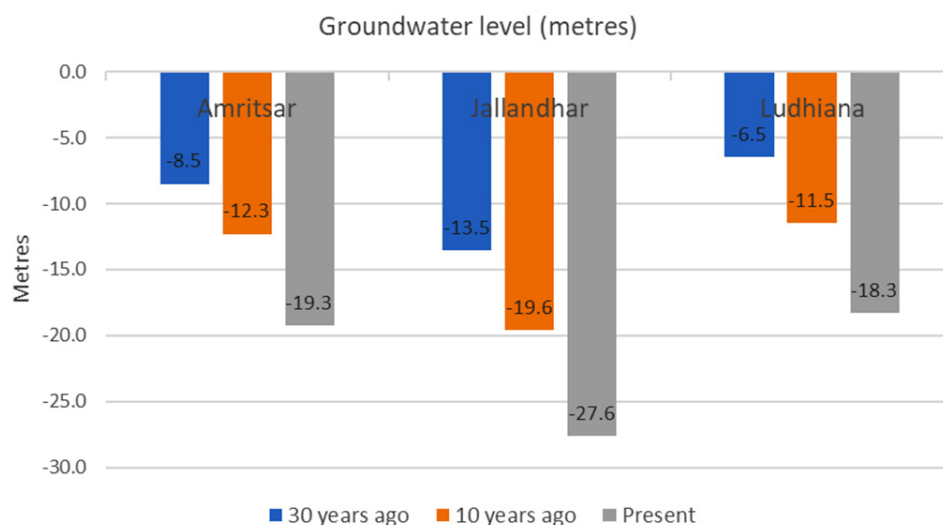


Figure 3 Decline in the water table

On the supply side, about 17% recommended the promotion of rainwater harvesting and 13.2% supported an increase in the use of canal water (Table 6). Smallholder farmers favoured rainwater harvesting, and large farmers felt that increasing the use of canal water would improve the overall supply of water for irrigation.

On the demand side, more than 27% preferred water-saving technologies and practices as the best way to ensure the sustainability of water use—provided comparable returns and efficient marketing facilities are available—and 17% chose crop diversification, or a shift to crops such as maize and vegetables.

Smallholders favoured technologies and practices and large landholders favoured crop diversification. About 6% of the farmers felt that the government should charge for electricity and 3.3% felt that the use of tube wells for agriculture should be restricted. Relative to

smallholders, farmers with large landholdings were more in favour of restricting the use of tube wells.

Overall, farmers' preferences were in line with the expert views. If a long-term strategy for ensuring the sustainability of water use in Punjab agriculture were drawn up, implementation and adoption would be straightforward.

The idea of crop diversification has existed in Punjab since the mid-1980s. But although many experts and committees have recommended that over 1 million ha be shifted away from paddy to sustain the groundwater resources and enhance farmers' income (Johl 1986; Johl 2002), farmers have not shifted their cropping pattern (Chattre, Devalkar, and Seshadri 2016) because the profitability is lower for alternatives like maize, cotton, pulses, oilseeds, fruits, and vegetables and the production and marketing risk higher.

Table 6 Farmers' suggestions to improve water use efficiency (by farm size, %)

Suggestions	Marginal	Small	Semi-medium	Medium	Large	Overall
Rainwater harvesting	34.9	34.2	4.3	11.1	11.1	17.0
Increasing the use of canal water	11.9	11.1	6.7	22.2	22.2	13.2
Water-saving technologies and practices	29.4	29.9	34.9	17.8	17.8	27.2
Crop diversification	1.8	6.0	30.6	14.4	14.4	17.0
Pricing of electricity	7.3	7.7	5.3	7.8	7.8	6.0
Restricting new tube well connections	1.8	2.6	2.4	7.8	7.8	3.3
Others	12.8	8.5	15.8	18.9	18.9	16.3

Table 7 Farmers' suggestions for promoting crop diversification in Punjab (%)

Suggestion to promote crop diversification	Marginal	Small	Semi-medium	Medium	Large	Overall
Remunerative prices for alternative crops	67.0	58.1	84.7	58.7	66.7	70.3
Awareness and capacity building	20.2	19.7	8.1	26.7	-	13.7
Establishment of processing industries	-	1.7	1.0	5.3	5.6	2.2
Assured marketing	10.1	17.9	4.8	2.7	14.4	9.5
Others	2.8	2.6	1.4	6.7	13.3	4.3

This study sought suggestions from farmers on promoting crop diversification in Punjab. More than 70% suggested that the prices for alternative crops need to be as remunerative and profitable as paddy (Table 7). The prevailing market prices for these crops are much lower than the minimum support price, and procurement is not assured; that is why farmers do not diversify and farm these crops. Besides, 13.7% of farmers said that the government needs to train farmers in cultivating these crops and build their capacity to reduce production and marketing risks. Almost 10% of the farmers noted that assuring the marketing of alternative crops can make it easy to shift from paddy. Only 2.2% said that the agro-processing industry in Punjab needs to be strengthened to promote crop diversification. The suggestions were unanimous across farm sizes.

The government needs to assure markets and remunerative prices for farmers in Punjab to shift to alternative crops. Several state governments have made small-scale interventions recently, but no outcome yet can yield a clear large-scale strategy.

Awareness, adoption, and capacity-building needs for sustainable options

The use of groundwater in Punjab can be made sustainable by the adoption and use of water-efficient technologies and practices such as direct seeding of rice (DSR), drip irrigation, laser land levelling, sprinkler irrigation, rainwater harvesting, and the use of tensiometers and soil moisture sensors (Vatta and Taneja 2018; Singh, Gajri, and Arora 2001; Kukal, Hira, and Sidhu 2005; Aggarwal et al. 2009).

Almost all the farmers surveyed are aware of laser land levelling, and more than 83% have adopted it (Table 8), because of the yield advantage from levelling, which may not be the case for other options (Naresh et al. 2014; Jabran et al. 2015; Ullah and Datta 2018). But, despite considerable awareness, the adoption and use

of the other technologies and practices is poor: about 17% of the farmers surveyed adopted raised bed cultivation, less than 5% adopted the other technologies and practices, and the adoption of drip irrigation was negligible.

Most of the farmers (37.7%) said that adopting the technologies and practices raises the fixed and variable costs. And 8% said that they do not know how to use these and that is why adoption reduces productivity (Table 9). The poor rate of adoption is cause for concern. The state government can ease the farmers' apprehension by making them aware of the economic and ecological benefits of adoption, build their capacity, and incentivize the adoption of these measures. And farmer-level organizations, NGOs, and gram panchayats need to supplement the efforts. However,

Table 8 Awareness and adoption of water-saving technologies and practices in Punjab (%)

Technology/practice	Awareness	Adoption
Laser land levelling	97.7	83.2
Direct seeding of rice	69.3	4.2
Drip irrigation	61.7	0.2
Sprinkler irrigation	67.7	2.0
Raised bed cultivation	45.3	17.2
Rainwater harvesting	23.0	1.5
Tensiometer/soil moisture sensor	21.0	2.5

Table 9 Why farmers do not adopt water-saving technologies (%)

Reasons	% of farmers
Rise in cost/fall in yield	37.7
Technology did not work	8.1
Lack of technical guidance	8.0
Others	46.2

Table 10 Farmers' sources of information, training, and decision-making

(%)

Source	Access
Fellow farmers/own experience	51.3
State Agricultural University*/Department of Agriculture	18.2
Primary Agricultural Cooperative Societies (PACS)	14.1
Web sources/mobile applications	5.2
Newspapers/TV/radio	5.1
Commission agents/input dealers	4.4
Other sources	1.7

Note * Includes Krishi Vigyan Kendras

the government's physical and financial support is a prerequisite.

Ongoing free electricity to agriculture is the other important reason for the poor adoption (Gulati, Roy, and Hussain 2017). We should explore the possibility of reorienting electricity subsidies for agriculture to make water saving the inevitable outcome. This study finds that low-cost water-saving options and their standardization, and capacity-building, will eliminate the production risk and the economic disadvantage of adoption. To invigorate capacity-building efforts, farmers must be encouraged to have access to more effective sources of information and training. Table 10 indicates the current access of farmers to information and training.

Most farmers (51.3%) rely on fellow farmers and their own experience for information. That might be the biggest constraint in developing the capacity to adopt and use water-efficient technologies and practices. More than 18% obtained information through Punjab Agricultural University and the State Department of Agriculture, followed by Primary Agricultural Cooperative Societies (14.1%). A tiny proportion of farmers relied on information from input dealers/commission agents for adopting water-saving options. Interestingly, more than 10% of the farmers depend on web sources, mobile applications, video and print media to enable decision-making.

Conclusions and policy suggestions

Through changes in hydrological cycles, climate change has adversely affected the availability and sustainability of freshwater (Kundzewicz et al. 2007).

The effects of climate change, exemplified by the diminishing availability of water, are pervasive, intense, and extensive. Climate change and variability are particularly detrimental to agriculture because the insufficiency of water can curtail the area under cultivation by 9% by 2050 (Marshall et al. 2015; Rosa et al. 2018) and cause a water crisis that exacerbates the demand–supply gap in water for agriculture—the main reason for the agricultural crisis (Mizyed 2008; UNO 2009).

Groundwater constitutes 89% of freshwater use, of which 70% is appropriated for agriculture; the use of water in agriculture is the prime factor in the fall of the water table, and so groundwater must be used efficiently (Dumars and Minier 2004). Agriculture is water-dependent, and warm and dry regions cater to almost 50% of the world food demand. The depletion of groundwater resources worldwide is inevitable; by 2025, the depletion is projected to be six times the depletion in 1900 (Rockstrom et al. 2009; Sivakumar 2011). If not checked, the over-exploitation of water reserves will affect agricultural growth and the most impoverished strata of society, including small farmers (Marshall et al. 2015).

Groundwater fully or partially irrigates the operational holdings in Punjab. Where the canal water is not sufficient, farmers use groundwater. With a 10–15 hp tube well, it is possible to irrigate only about 2.5 ha of paddy (water-intensive but most remunerative kharif crop). The potential of water-saving technologies and practices is huge but, with the exception of the laser land leveller, awareness of these is low and adoption even lower, because the costs are higher, training is

not provided, and farmers are concerned that productivity may decline. These technologies and practices need to be promoted by agricultural extension services through the Department of Agriculture and Farmers' Welfare, Department of Horticulture, state agricultural universities, and Krishi Vigyan Kendras, because most farmers rely on their fellows for information, and they may not have all the information farmers need to make a decision.

Farmers that have large landholdings believe that augmenting supply canal water can improve the supply of irrigation water. Smallholders prefer harvesting rainwater. Both crop diversification and water-saving technologies and practices can reduce the use of groundwater in agriculture. But the production and marketing risk is higher in alternative crops, and farmers, especially smallholders, prefer to farm paddy or adopt water-saving technologies and practices. Irrespective of landholding size, most farmers feel that paddy cultivation is the prime reason for the depletion of groundwater resources, but farmers cultivate it notwithstanding, because prices are remunerative and procurement is assured. Punjab has been trying to promote crop diversification for more than three decades, with little success. Most farmers want the government to assure the procurement of alternative crops at remunerative prices. Farmers need capacity building to understand the value of producing alternative crops to market requirements.

A shift from the water-intensive cropping system is called for. The shift should encourage the growth of a wide range of drought-resistant crops. Tweaking the technologies and water management practices is crucial for making the use of groundwater sustainable (Pingali and Rosegrant 1994). The demand-side interventions must be integrated carefully, the trade–food–water nexus addressed, and integrated landscaping approaches adopted (Mizyed 2008; Dankova 2016). An integrated framework—encompassing policies, strategies, and programmes to adapt agriculture to water scarcity—needs to be tailored to region-specific circumstances and requirements (Green et al. 2020).

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