Groundwater depletion in Central Punjab: pattern, access and adaptations

*Satvir Kaur and Kamal Vatta**

Based on primary data collected from 105 farming households spread across three districts and nine villages of central Punjab, this study examines groundwater depletion and consequent shifts of the farmers from centrifugal to submersible pumps. It also documents adaptation strategies of farmers in response to groundwater depletion. Owing to groundwater depletion, borewell deepening started in the 1980s and was witnessed on almost all the farms by the mid-1990s. The shift from centrifugal to submersible motors followed the S-shaped curve, which was usually observed in the adoption process of new technologies and practices. There was increase in investments on shifting to submersible pumps and the small farmers also opted for sharing of motors in order to reduce the burden of increasing investments. There were also some shifts towards alternative crops in the kharif season on small farms in response to declining access to irrigation water due to groundwater depletion in central Punjab. Some farmers were also resorting to water saving practices such as laser levelling and direct seeding of rice. Promotion of water saving technologies and practices may reduce groundwater depletion and improve access of the small holders to water.

Keywords: Adaptations, centrifugal and submersible pumps, groundwater depletion, irrigation.

INTENSIVE agriculture dominated by paddy–wheat monoculture has led to overexploitation of natural resources in Punjab, especially groundwater. Currently, out of 20 million tubewells in the country, almost 1.3 million are in Punjab, contributing to fast-paced groundwater extraction and its depletion. The problem of overexploitation of groundwater resources is most severe in central Punjab, usually called sweet water zone and dominated by rice crop in the *kharif* season. While the average annual fall in groundwater table in the central Punjab was about 17 cm during the 1980s and about 25 cm during the 1990s, it was alarmingly high at 91 cm per annum during 2000–2005 (ref. 1). Out of 142 blocks in the state, water table is declining in 110 blocks due to over-extraction of water than recharge. By 2023, the water table depth in central Punjab is projected to fall below 70 feet in 66% area, below 100 feet in 34% area and below 130 feet in 7% area[2].

Due to the depletion in groundwater resources, irrigation expenditure for rice and wheat crops has increased significantly in the last decade[3]. The increased cost of well deepening and pump replacement (from centrifugal to submersible) has contributed to increasing incidence of farmers' indebtedness with relatively more adverse effect on the small and marginal farmers who lack sufficient resources to finance such investments. As a result, many smallholders may lose access to groundwater for irrigation, which may adversely affect crop productivity and hence the farm incomes. Further, such a phenomenon may influence the crop choices and may compel farmers towards inferior alternatives of access to groundwater and farming practices.

The negative impact of intensive agriculture on groundwater depletion has been well-documented but with a larger focus on the extent and causes of depletion and on the implications for cost of irrigation, farm investments, power consumption and subsidy. Micro-level evidence on the timeline of groundwater depletion and equity aspects of access to groundwater due to increasing investment needs, however, is completely lacking. This study, therefore, makes an attempt to examine the timeline of groundwater depletion, the shift to submersible pumps, the sources of such investments and the adaptation strategies of various farm size groups in response to the groundwater depletion.

Satvir Kaur is at Punjab Agricultural University, Ludhiana, Punjab 141 004, India; Kamal Vatta is in the Centers for International Projects Trust, K-37, Lower Ground Floor, Green Park Main, New Delhi 110 016, India.
*For correspondence. (e-mail: kmlvatta@yahoo.com)

Database and methodology

This study was based on the primary data collected from 105 farming households of the central Punjab by following multi-stage random sampling procedure. At the first stage, three districts of Moga, Patiala and Jalandhar were selected randomly out of 12 districts in central Punjab. Later, three villages were randomly selected from each of the selected districts, making a total of nine villages for the study. There were a total of 321 villages in Moga, 1054 villages in Patiala and 934 villages in Jalandhar district. The farming households were the ultimate stage of sampling. A complete list of all the farming households in each selected village was prepared with further classification of the households into small (below 2 ha), medium (above 2 ha and below 6 ha) and large (6 ha and above) farm households, based on size of the operational holding. Finally, a sample of 10–13 farming households from each selected village, almost equally distributed across three size categories, was selected for data collection.

Data on various parameters such as family size, education, operational holdings, important sources of household income, access to different credit sources, etc. were collected by personal interview method. Information was also collected on access to irrigation sources, ownership of electric motors, horse power, cropping pattern, history of well deepening and adaptation strategies of the sampled farming households.

Trends in groundwater depletion and subsequent investments on irrigation

It is widely argued that following of intensive agricultural practices in Punjab had an adverse impact on groundwater resources. Introduction of high yielding varieties of paddy during the early-1970s facilitated huge shift in the area under this crop. Water requirement of paddy is much higher than that of alternative crops. While the area under rice crop was less than 5% of the gross cropped area in Punjab during the early 1970s, the proportion increased to more than 35% in the recent times. Demand for water for irrigation increased rapidly and surpassed the sustainable levels of supply in the long-run. The demand–supply gap in water use in agriculture exerted an intense pressure on groundwater as this gap was largely sourced from the groundwater resource. Continuous overexploitation of groundwater resources led to steep fall in the groundwater level.

The fall in groundwater level had many adverse implications for the farming community. Electric motors were placed at the surface of Earth during the 1970s, but the fall in groundwater table necessitated frequent deepening of the borewells and placing of the motors deep in the deepened wells to draw sufficient water for irrigation. It also required gradual increase in the power of installed motors as more power was required to draw groundwater from deeper water table. During last few decades, most of the farmers have shifted from centrifugal to submersible pumps. Such a phenomenon of depleting groundwater and subsequent deepening of borewells and shifting to submersible pumps required significant investments from the farmers and also led to significant increase in farmers' debt.

The phenomenon of deepening of borewells and subsequent shift from centrifugal to submersible pumps was documented on the basis of farmers' responses. The farmers were asked to report the year when their electric motors were last seen functioning at the surface before deepening of the borewells started. It was supposed that the farmers started deepening the borewells thereafter and placing the motors in the deepened wells for drawing groundwater for irrigation. As the information is based on recall, it must be interpreted with some caution as the reported timeline may vary slightly from the actual situation at the macro level. About 20% of the farmers have reported that the latest year when the motors were on the surface was in the mid-1970s, though majority believed the deepening to have started mainly during the 1980s as revealed by the cumulative proportion of farmers reporting such deepening (Figure 1). Almost all the farmers believed that none of the electric motors were on the surface after 1995. Hence, it was largely in the 1980s and mid-1990s when deepening of the borewells started due to depleting groundwater resources and sharp increase in the area under paddy cultivation. Deepening of tubewells required frequent investments from the farmers which led to an increase in the fixed costs of farming as well as rising incidence of farm debt.

Deepening of the borewells was not a one-time phenomenon, but farmers had to resort to such deepening multiple times. The farmers deepened their wells by 5–10 feet, based on the extent of fall in the water table and it happened many times before the shift from centrifugal to submersible pumps. Table 1 provides the distribution of final depth of borewells across each farm-size category before the shift to submersible pumps. More than 60% of the farmers shifted to submersible motors when the depth of the borewell reached 40–50 feet or 50–60 feet. The proportion of small farmers shifting to submersible pumps at borewell depths of 20–30, 30–40, 40–50, 50–60 and 60–70 feet were 8.8%, 17.6%, 32.4%, 29.4% and 11.8% respectively. The respective proportions of medium farmers were 4.3%, 4.3%, 32.6%, 30.4% and 19.6% and that of large farmers were 1.5%, 13.4%, 41.8%, 19.4% and 22.4%. On the medium and large farms, 8.7% and 1.5% farmers reported the shift when the depth of the well exceeded even 70 feet.

The shift from centrifugal to submersible pumps also took place over a period of time. The farmers' response revealed that the shift happened during the last 15 years (Figure 2). About 12% of the farmers revealed that the shift occurred more than 12 years ago, though 32.7% of the farmers reported to have shifted to submersible motors about 9–12 years ago. While 34.6% of the farmers reported such shift about 6–9 years ago, it was almost a relatively recent phenomenon for more than 20% of the

Table 1. Distribution of the depth of tubewell before shifting to submersible pumps (number)

Depth (feet)	Small	Medium	Large	Overall
20 to 30	3 (8.8)	2 (4.3)	1 (1.5)	6 (4.1)
30 to 40	6 (17.6)	2 (4.3)	9 (13.4)	17 (11.6)
40 to 50	11 (32.4)	15 (32.6)	28 (41.8)	54 (36.7)
50 to 60	10 (29.4)	14 (30.4)	13 (19.4)	37 (25.2)
60 to 70	4 (11.8)	9 (19.6)	15 (22.4)	28 (19)
Above 70	–	14 (8.7)	1 (1.5)	5 (3.4)

Figures in parentheses indicate percentage of total number of wells for a given farm size category under different depths.

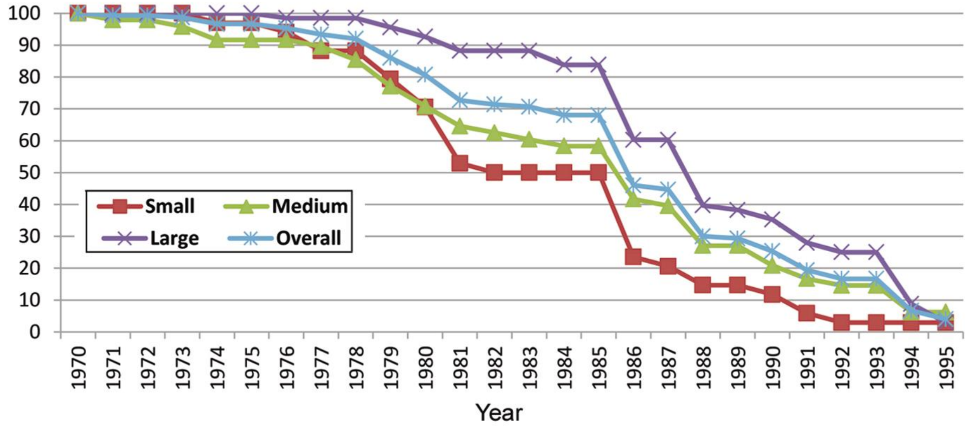

Figure 1. Cumulative proportion of farmers reporting when their motors were last seen on the surface.

farmers. Further examination of the pattern of shift across various farm size categories reveals that the medium and large farmers shifted from centrifugal to submersible pumps relatively earlier than their smaller farm counterparts. More than 60% of the smallholders reported the shift during the last 9 years, while the proportion of medium and large farmers was about 55% and 52% respectively. It may occur due to relatively poor financial position of the smallholders who could not afford huge investments on such a shift from centrifugal to submersible pumps. The shift was less than 6 years for more than 28% of the small farmers, as compared to about 20% of the medium farmers and about 16% for the large farmers.

Further examination of the frequency and cumulative frequency revealed that majority of the shifts appeared to have occurred during 2001–2005. The frequency of shifts appeared to follow normal distribution. The cumulative frequency distribution of the pattern of shifts from centrifugal to submersible pumps formed the S-shaped curve over time. This pattern of adoption is in agreement with the Roger's thesis that adoption follows an S-shaped pattern where the initial rate of adoption is very slow due to lack of awareness. Later, the adoption takes place exponentially till it is widely adopted by almost all and then the curve becomes flat again as the adoption is almost complete. The shift from centrifugal to submersible pumps was also the adoption of advanced technology which facilitated more efficient use of electric motors to draw water from the deeper levels. The shift appears to have been completed across most of the farmer categories in about a decade.

Sources of investment on irrigation

It is well-known that gradual deepening of borewells and then a shift to submersible pumps required large amounts of investment from the farmers. Although electricity was provided free to the farmers in Punjab, the fall in groundwater level led to increase in the fixed costs of farming, as more investments were made to sustain the access to groundwater for irrigation. The average amount of investment on shifting to submersible motors was Rs 46,802 on small farms, Rs 116,295 on medium farms and Rs 172,057 on large farms respectively (Table 2).

Almost 90% of such investment was being sourced from own savings on large farms, whereas this proportion was much less at 78.8% on medium farms and 57.5% on small farms. The fact that depletion of groundwater resources was necessitating increased investments and was pushing the small farmers more into the debt burden was evident from the proportion of such investments being

Table 2. Sources of investments for shift to centrifugal pumps

Particulars	Small	Medium	Large	Overall
Own savings	26,911 (57.5)	91,640 (78.8)	15,3819 (89.4)	87,094 (79.3)
Commercial and cooperative banks	3,884 (8.3)	3,256 (2.8)	688 (0.4)	3,075 (2.8)
Commission agents and money lenders	14,509 (31.0)	21,399 (18.4)	10,688 (6.2)	16,804 (15.3)
Relatives, friends and others	1,498 (3.2)	–	6,882 (3.9)	2855 (2.6)
Total	46,802 (100)	11,6295 (100)	17,2057 (100)	10,9828 (100)

Figures in parentheses indicate percentage of total finance for a given farm size category.

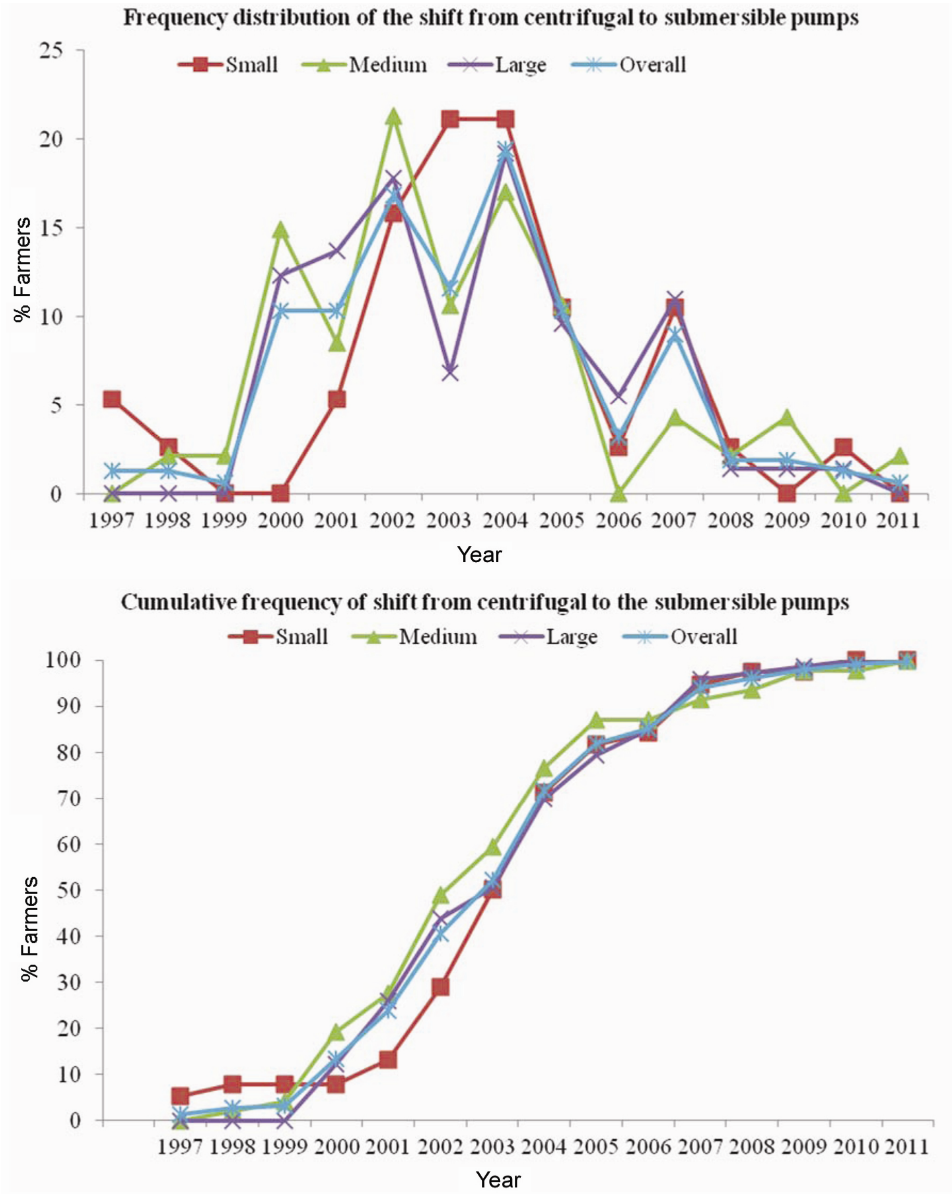

Figure 2. Frequency and cumulative frequency of shifts from centrifugal to submersible pumps in central Punjab.

sourced through the commission agents/money lenders. Small farmers were borrowing 31% of their total investments from the commission agents/money lenders, who usually charge much higher rates of interest than institutional sources. Relatively larger borrowings from this source may be cited as an important reason for increasing indebtedness among the small and marginal farmers in the state. Dependence on commission agents and money

Table 3. Cropping pattern of the sample farm households, Punjab

Crop	Small farms		Medium farms		Large farms		Overall	
	2011–2012	2001–2002	2011–2012	2001–2002	2011–2012	2001–2002	2011–2012	2001–2002
Kharif season								
Rice	38.94	44.36	39.40	42.43	44.74	44.74	42.86	44.04
Maize	–	–	0.61	0.29	–	–	0.15	0.10
Cotton	–	–	0.61	0.59	–	–	0.15	0.15
Sugarcane	0.85	–	0.61	–	0.67	0.67	0.64	0.44
Fodder	8.51	5.64	7.26	6.10	3.36	3.36	4.91	4.38
Others	1.23	–	1.81	0.59	1.57	1.57	1.64	1.11
Rabi season								
Wheat	38.30	40.23	42.86	43.96	42.27	42.94	42.11	42.98
Sunflower	2.13	1.88	–	–	–	0.90	–	0.73
Potato	1.06	0.94	1.21	1.17	2.69	2.24	2.13	1.80
Others	8.08	6.95	5.63	4.87	4.70	3.58	5.41	4.27
Gross cropped area (ha)	1.88	2.13	6.61	6.82	17.86	17.86	8.06	8.23

All figures are percentages of gross cropped area.

Table 4. Adaptation/mitigation strategies reported in response to depleting water resources

Farmers reporting (%)	Small farms	Medium farms	Large farms	Overall
Decline in the area under paddy	13.9	9.6	3.3	9.5
Increase in the area under basmati	7.7	22.2	36.7	21.0
Starting of direct seeding rice	–	2.8	6.7	2.9
Use of water saving technologies	5.1	16.7	23.3	14.3
Sale of agricultural land	15.4	10.7	–	11.4
Average area of land sold (ha)	0.76	0.84	–	0.80

lenders for such investments was 18.4% on medium farms and just 6.2% on large farms. It is clear that the debt burden due to depleting groundwater resources declined with an increase in the farm size and it pinched the smallholders more.

Access to groundwater and adaptation strategies

It is hypothesized that faster depletion of groundwater, necessitating increased investments in irrigation might have reduced the access of smallholders to groundwater as they might be owning less number of electric motors as compared to their larger counterparts. In addition, adaptation strategies for various categories of farm households have also been documented to determine their strategies in response to declining groundwater resources.

On average, a small farmer owned one-third of an electric motor (due to sharing), a medium farmer owned more than one motor and a large farmers owned two electric motors. While all the medium and large farms had at least one electric motor under complete ownership, almost 64% of the small farms did not have any completely owned motor and were sharing it with their relatives or neighbouring farmers to reduce the burden of high investments. As medium and large farmers owned more than one motor, 45% and 6% of them were opting to share the second and third motors respectively. Almost half of the small farmers and 30% of the medium farmers cited high investments and smaller landholdings as important reasons for their opting to share the electric motors. It reflects that depletion in groundwater resources and requirement of very high investments on electric motors adversely affected the access of small farmers to groundwater resources, which pushed them to the shared mode of electric motors to draw groundwater for irrigation.

Decline in access to groundwater may have a direct impact on the cropping pattern and may force the farmers to opt for less water-consuming crops. In order to study the change in cropping pattern, information on the current cropping pattern and of a decade ago was obtained from the farmers through recall method and the results are provided in Table 3. As there were incidences of sale of land by small and medium farmers, changes in the cropping pattern are expected not only due to the depletion in groundwater resources and consequent decline in access to groundwater, but also, by the sale of land which caused a decline in the net area sown on these two farm size categories. There was considerable decline in the area under rice crop and the area under sugarcane, fodder, potato, maize and pulses increased on the small and medium farms, over time. However, the shift in area was not very large which might be due to higher production and marketing risks involved in the production of alternative crops. Most of the changes in cropping pattern occurred during the *kharif* season and not during the *rabi* season. The changes, however, indicate that there were attempts to adapt to the changing access to groundwater resources.

Apart from the changes in cropping pattern, there are some other adaptation options, which have the potential to cause a significant reduction in the water use and may help in countering the adverse impact of decline in access to groundwater resources. About 10% of the farmers reported a decline in the area under paddy owing to the depletion in groundwater resources (Table 4). Decline in the area under paddy was inversely related to the size of operational holding and smallholders were reducing the area under paddy relatively more than large farm owners. About one-fifth of the farmers reported an increase in the area under basmati rice in response to the decline in water table. As basmati rice is transplanted late, it consumes relatively less water than the normal duration varieties of paddy. Large size farms were opting more for basmati varieties than the small farmers. About 3% of the farmers also adopted direct seeding of rice. More than 14% of the farmers opted for water saving technologies, mainly laser levelling, to reduce water use in agriculture and the proportion of such farmers was relatively more on large farms. There were many incidences of sale of agricultural land, though the sale of land may not be entirely attributed to the decline in water table.

Conclusions

Depletion of groundwater led to frequent deepening and shift from centrifugal to submersible pumps. The phenomenon of borewell deepening started in the 1980s and covered almost all the farms by 1995. The shift from centrifugal to submersible pumps followed an S-shaped cumulative frequency curve. Smallholders increasingly opted for sharing of electric motors due to rising costs. Sharing of motors adversely affected the timing and adequate access to groundwater. Farmers were opting for water saving practices but to a lesser extent. Smallholders were reducing the area under rice crop. There is a need to reorient policy to improve access of the smallholders to groundwater. Use of water saving technologies needs to be promoted to check groundwater depletion, which may improve access of the smallholders to groundwater.

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Received 8 June 2014; revised accepted 14 November 2014