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Unsustainable Groundwater Use in Punjab Agriculture: Insights from Cost of Cultivation Survey

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ABSTRACT

Groundwater depletion has emerged as the major constraint in sustaining growth in agriculturally advanced state of Punjab. The study unravels unsustainable groundwater use in crop production using unit-level cost of cultivation survey data. The deterioration in groundwater resources is the outcome of technology and policy led shift in cropping pattern (towards paddy), irrigation source (towards groundwater) and energy source (towards electricity) in Punjab. Presently, total annual groundwater draft in the state is 72 per cent higher than the sustainable limit of 20 BCM. Agriculture being the largest user of groundwater draft bears the prime responsibility in averting groundwater crisis. Paddy emerged as the most water-guzzling crop consuming 45 to 88 per cent higher groundwater than other crops. Consequently, paddy had highest groundwater footprints (cum/kg) and lowest groundwater productivity (Rs./cum). Further, there exists large scale inefficiency in groundwater use for paddy cultivation. The optimum level of groundwater use for paddy cultivation should be about 52 per cent less than the present level of 1.2 ha-metre. Interestingly, large farmers emerged as more efficient user of groundwater resources and productive as compared to farmers with smaller land holdings. The strategy to ensure sustainability must include both groundwater supply augmentation and demand reduction measures with greater emphasis on improving water use efficiency and curtailing non-productive use of groundwater resources.

Keywords: Groundwater, Footprints, Productivity, Inefficiency, Cost of cultivation data.

JEL: Q15, Q16

I

INTRODUCTION

The land-augmenting and productivity-enhancing role of groundwater has been well documented in India and elsewhere (Shah *et al.*, 2003). As an integral component of Green Revolution technology, groundwater irrigation played a catalytic role in averting food crisis in India during mid-sixties. But, injudicious utilisation and excessive reliance on this precious natural resource has resulted into emergence of a groundwater crisis, especially in North-West region of the country (Dhawan, 1995; Gandhi and Namboodiri, 2009; Srivastava *et al.*, 2014a). Punjab, agriculturally the most advanced state, stands at an extreme end of over-exploitation of groundwater (Singh, 2004, 2012; Kulkarni and Shah, 2013). As per the Central Groundwater

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Board (CGWB) estimates, total annual draft of groundwater in Punjab is 72 per cent higher than the net annual replenishable level of 20 billion cubic metre (BCM). The consequences of higher withdrawal over the net recharge are the decline in groundwater table and associated negative externalities such as rising cost of deepening and replacing (from centrifugal to submersible pumps) of existing wells, installing new wells, inequitable groundwater access, reduced agricultural profitability, etc. (Shah, 1991; Moench, 1992; Singh and Kalra, 2002; Kaur and Vatta, 2015).

Agriculture sector being the largest user of groundwater resources (CGWB, 2014) bears the prime responsibility in averting the groundwater crisis. Many studies have elucidated several hydrological (Gupta, 2009; Srivastava *et al*. 2014b), socio-economic (Nagaraj and Chandrakanth, 1997, Sarkar, 2011), institutional (Ballabh, 2003, Ghosh *et al*., 2014) and policy (Sekhri, 2013, Sarkar and Das, 2014) related aspects of groundwater management, but without any systematic effort towards volumetric assessment of groundwater draft and extent of its over (under) use in crop production in the farmer's field. CGWB, a nodal agency for monitoring groundwater resources, carries out periodic assessment of groundwater use for different sectors (irrigation, domestic, industry) of the country. But such estimates are not available for individual crops within the agriculture sector. The present study attempts to fill this void and estimates the volume of groundwater use for irrigating different crops in Punjab using unit-level cost of cultivation survey data of Directorate of Economics and Statistics (DES) and groundwater level data of CGWB. The study further evaluates whether groundwater utilisation in crop production is optimal or not, pinpoints the possible reasons of its over-use and provides empirical evidences for technological and policy interventions to ensure sustainable groundwater use in Punjab agriculture.

II

BACKGROUND

Status of Groundwater Resources

Total annual replenishable groundwater potential in India has been estimated as 433 billion cubic meters (BCM) and rainfall contributes 74 per cent in total groundwater recharge (Table 1). Out of total replenishment, 398 BCM can be made available for different uses annually, keeping aside 34 BCM for natural discharge. With an annual groundwater draft of 245 BCM (irrigation consuming 91 per cent of total draft), overall groundwater development in the country is 62 per cent. Thus, groundwater can be developed further in the country as a whole. However, groundwater development is not uniform across geographical regions (Srivastava *et al*., 2014a) and Punjab state has witnessed an extreme level of groundwater over-exploitation. Total annual groundwater draft in the state is 14.56 BCM higher than the sustainable limit of 20 BCM leading to a drastic decline in groundwater level.

TABLE 1. GROUNDWATER AVAILABILITY AND UTILISATION

Particulars (1)	India (2)	Punjab (3)
Annual replenishable GW resources (BCM)	432.72	22.53
Rainfall (per cent)	74.32	31.73
Other sources(per cent)	25.68	68.27
Net groundwater availability (BCM)	398.19	20.32
Annual groundwater draft (BCM)	245.05	34.88
Irrigation (per cent)	90.74	97.96
Domestic and industrial use (per cent)	9.26	2.04
Stage of groundwater development (per cent)	62	172
Extent of over-use of groundwater (BCM)	- 153.14	14.56

Source: CGWB (2014).

During the past 14 years, average groundwater level has declined from 8 meter below ground level (m bgl) in the year 1999 to 15 m bgl in 2014 at an alarming rate of 43 cm per annum. The categorisation of monitoring wells of CGWB into different water level classes revealed a noticeable shift in proportion of wells from shallow water level category to deep water level category (Table 2). Presently, more than 60 per cent of total wells have groundwater level of 10 m bgl or more. Declining groundwater level below 8-10 m bgl puts heavy financial burden because at this level surface (centrifugal) pumps become infeasible to extract groundwater and farmers have to replace them with costlier submersible pumps (Sekhari, 2013). The deteriorating state of groundwater in Punjab is clearly reflected from the categorisation of about 80 per cent of the total assessed administrative blocks (138) as “over-exploited” or “dark blocks” by the CGWB. It is worth mentioning that declining groundwater level is not the only problem related to groundwater resources. The declining groundwater table in central Punjab is accompanied by water-logging[1] situation in south-western part of the state (Government of India, 2013). The groundwater level in Punjab varies from near surface upto 40 m bgl with the mean value of 15 m bgl. The regional variation in groundwater use can be known from the

TABLE 2. TREND IN DISTRIBUTION OF MONITORING WELLS ACROSS GROUNDWATER LEVEL CLASSES IN PUNJAB

(*per cent*)

Groundwater level (m bgl) (1)	1990 (2)	2000 (3)	2010 (4)	2013 (5)
< 5	33.84	30.42	20.74	18.14
5 - 10	42.24	39.15	20.37	18.14
10 - 20	21.98	28.57	39.26	35.18
20 - 40	1.94	1.85	18.15	27.88
> 40	–	–	1.48	0.66
No. of wells	464	378	270	452

Source: Authors’ estimates based on data collected from CGWB, Government of India.

fact that the level of groundwater development varies from only 21 per cent in Dharkalan block of Gurdaspur district to as high as 416 per cent in Ahmedgarh block of Sangrur district (CGWB, 2014). The wide heterogeneity in groundwater resource makes management of this precious resource complex and necessitates technological and policy interventions at disaggregate level of geo-political boundaries.

The strategy to ensure sustainability warrants both groundwater supply augmentation and demand reduction measures. In Punjab, rainfall has limited role to augment groundwater supply due to low annual precipitation of about 472 mm during a short span (Government of Punjab, 2012). Rainfall recharges only 32 per cent of replenishable groundwater (against the national average of 74 per cent) and bulk of groundwater recharge takes place from other sources (68.27 per cent) such as return flow from irrigation, seepage from canal, recharge from tanks, ponds and water conservation structures (Table 1). Thus, integrated water resources management assumes a vital role in groundwater augmentation. But, interlinked nature of groundwater and surface water is not recognised in India. As per the recent minor irrigation census (2011), more than 60 per cent of shallow and deep tubewell were constructed outside the command area of surface irrigation and less than one per cent of the total wells were used for augmenting groundwater supplies. Further, slow speed of natural replenishment than the continued exploitation necessitates construction of artificial recharge structures for speedy augmentation. Many artificial recharge schemes are being implemented by different government and non-government agencies (CGWB, 2013). But, artificial recharge alone may not be sufficient to avert the groundwater crisis in the state because the quantity of non-committed surplus surface water in Punjab for artificial recharge has been estimated to be only 1201 million cubic metres (MCM) against the requirement of 70,071 MCM (CGWB, 2013). Given a limited scope for augmenting groundwater supplies, emphasis must also be extended to reduce the demand for groundwater by competing users. Agriculture sector, the predominant consumer for groundwater (97.96 per cent), bears the sole responsibility in sustainable use of groundwater resources. The groundwater use in agriculture can be reduced by curtailing excessive withdrawal as well as by improving water use efficiency in crop production. The information on the extent of groundwater use among different crops would help to frame suitable technological and policy interventions for ensuring sustainable use of groundwater in the state.

III

DATA AND METHODOLOGY

The study is primarily based on plot-level data collected under "Comprehensive Scheme for Cost of Cultivation of Principal Crops" of Directorate of Economics and Statistics, Ministry of Agriculture. The cost of cultivation survey (CCS) has been collecting a rich source of representative and comparable data on different aspects of farming across different regions of the country since 1970-71. However, this wealth of data has remained grossly under-utilised due to many administrative and non-administrative hurdles (Sen and Bhatia, 2004; Nawn, 2013). In the CCS, each sample household is surveyed consecutively for three years and the latest available data pertains to the period 2008-09 to 2010-11 (block year ending 2010-11). For Punjab, the plot-wise data was collected from the 300 representative households of 30 tehsils during each year of the block period (2008-09 to 2010-11) by the Punjab Agricultural University, Ludhiana, which is a nodal agency for this state. It is pertinent to note that the sample households of each tehsil are equally distributed among five different land-holding size groups. The data on groundwater level was collected from CGWB.

Estimation of Volume of Groundwater Extraction

The volume of total groundwater for irrigating major crops (paddy, wheat, cotton, sugarcane. maize) in Punjab was estimated as the product of irrigation hours and per hour groundwater draft (cum/hr). The irrigation hours (hrs/ha) for each crop were taken from plot-wise CCS data. AsCCS does not collect information on groundwater draft, it was estimated using the following formula (Srivastava *et al*., 2014b);

$$\text{Groundwater draft (lit/sec)} = \frac{\text{Hp} \times 75 \times \text{Pump efficiency}}{\text{Total head (m)}}$$

The information on horse power (Hp) of the pumps owned by the farmers was extracted from CCS dataset. For the households purchasing groundwater, average Hp of the pumps (estimated separately for electric and diesel) in respective tehsil was taken into consideration. Total head was estimated as sum of groundwater table (m bgl) and friction loss (10 per cent of water table). For submersible pumps additional depth of 11 metre was added to the total head after discussion with the experts because these pumps are placed far below the groundwater table. Pump efficiency was assumed to be 40 per cent (Srivastava *et al*., 2014b). As irrigation pumps vary in terms of type (centrifugal/submersible) and energy use (electric/diesel), per unit (cum/hr) and thereafter total groundwater draft (cum/ha) was estimated for each category of pump separately. The summation of groundwater draft from each category of pumps gave total groundwater use (cum/ha) for each crop cultivated by the farmer.

The crop-wise groundwater footprints (cum/kg) was estimated by dividing total groundwater use with the respective crop yield. Similarly, groundwater productivity (Rs./cum) was estimated by dividing value of output (main + by product) with the groundwater use.

Estimation of Groundwater Use Efficiency

The production function approach was used to examine efficiency in groundwater use for cultivation of paddy and wheat in Punjab. A pooled log-linear regression function was fitted between crop yield and production inputs using plot-level observations of the block year ending 2010-11. The general specification of the model is given below;

$$
\begin{aligned}
LnY_{it} = \alpha + \beta_1\, LnSEEDEXP_{it} + \beta_2\, LnFERT_{it} + \beta_3\, LnPPROTECTEXP_{it} \\
+ \beta_4\, LnLABOUR_{it} + \beta_5\, LnMACHIN_{it} \\
+ \beta_6\, LnGWUSE_{it} + \beta_7\, LnCROPAREA_{it} + \beta_8 D2010 \\
+ \beta_{89} D2011 + e
\end{aligned}
$$

where,

Y_{it}	=	crop yield (Kg/ha) for i-th plot in j-th year
$LnSEEDEXP_{it}$	=	seed expenditure (Rs./ha) for i-th plot in j-th year
$LnFERT_{it}$	=	fertiliser use (kg/ha) for i-th plot in j-th year
$LnPPROTECTEXP_{it}$	=	plant protection cost (Rs./ha) for i-th plot in j-th year (instecticide + pesticide + herbicide)
$LnLABOUR_{it}$	=	labour hours (hrs/ha) for i-th plot in j-th year
$LnMACHIN_{it}$	=	machine hours (hrs/ha) except irrigation pumps for i-th plot in j-th year
$LnGWUSE_{it}$	=	groundwater use (cum/ha) for i-th plot in j-th year
$LnCROPAREA_{it}$	=	area (ha) of the i-th plot in j-th year
D2010	=	dummy for the year 2009-10 (Reference year = 2008-09)
D2011	=	dummy for the year 2010-11 (Reference year = 2008-09)
e	=	Error term

The variables were expressed in natural logarithmic form. The estimated coefficient of LnGWUSE from the above model was used to estimate marginal physical product of groundwater (MPP_{GW}) in paddy and wheat.

$$MPP_{GW} = \beta_6 \times \frac{\bar{Y}}{\overline{GWUSE}}$$

$\bar{Y}$ and $\overline{GWUSE}$ are geometric means of crop yield and groundwater use, respectively. MPP_{GW} indicates the additional output which could be obtained from using an incremental unit of groundwater. The multiplication of MPP_{GW} with price of output gave marginal value product (MVP_{GW}). The MVP_{GW} was equated with the per unit cost of groundwater extraction (P_{GW}) to know whether groundwater is over-utilised (if $MVP_{GW}/P_{GW} < 1$) or under-utilised (if $MVP_{GW}/P_{GW} > 1$) in crop production. The optimum level of groundwater was estimated at the level where $MVP_{GW}/P_{GW} = 1$. The comparison of actual groundwater use (if over-utilised) with the optimum level indicates groundwater efficiency in crop production. The per unit groundwater cost (Rs./ha-metre) includes depreciation, interest, repair and maintenance expenses of installing and operating irrigation pumps and was taken as a proxy for price of groundwater (P_{GW}).

IV

RESULTS AND DISCUSSION

Groundwater Utilisation Pattern in Crop Production in Punjab

Within agriculture, the extent of groundwater use varies across different crops depending upon the pumping hours and average yield {cubic meter/hour (cum/hr)} of the pumps. The estimated per hour groundwater draft in the study area varied from 8.17 cum/hr to 349 cum/hr during TE 2010-11 depending upon the horse power of the pump used and heterogeneity in water level (Appendix 1). The groundwater draft of sample farmers' field was found to be comparable with CGWB estimates of ≤ 50 to ≥150 cum/hr in different aquifer zones of Punjab (Gupta, 2009). The product of per hour groundwater draft and pumping hours produces estimates of total volume of groundwater extraction for different crops grown in the farmers' field. It was found that Punjab farmers run tubewell for 285 hours to cultivate one hectare of paddy followed by 170 hours for sugarcane, 60 hours for wheat, 53 hours for maize and 46 hours for cotton (Table 3). The pump wise decomposition further revealed that more than 50 per cent of the groundwater irrigation is given using submersible pumps except for cotton and sugarcane. The dominance of submersible pumps for major crops indicates a deeper water table in large part of the state. For cotton cultivation, submersible pumps were not used primarily because it is grown in water-logging and salinity affected south-western part of the state. Due to salinity problem, farmers prefer canal irrigation and use groundwater as a source of supplementary irrigation. About 88 per cent of the cotton area of the sample farmers was irrigated using "tubewell + canal" source of irrigation followed by canal (9.17 per cent) and tubewell alone (1.80 per cent) during TE 2010-11.

TABLE 3. PATTERN OF GROUNDWATER EXTRACTION IN PUNJAB IN TE 2010-11

	Groundwater irrigation hours (hours/ha)				Share in total irrigation hours (per cent)		
Crops (1)	Diesel pump (2)	Electric centrifugal (3)	Electric submersible (4)	Total (5)	Diesel pump (6)	Electric centrifugal (7)	Electric submersible (8)
Paddy	11	124	150	285	4	43	53
Non-basmati	12	131	141	283	4	46	50
Basmati	9	98	183	290	3	34	63
Wheat	4	23	33	60	6	39	55
Cotton	22	21	3	46	48	46	6
Sugarcane	8	118	44	170	4	69	26
Maize	7	18	28	53	13	35	52

Source: Authors' estimate based on unit level CCS data of DES.

Among major crops, paddy was found to be the most water-guzzling crop with the groundwater use of 12151 cum/ha during TE 2010-11. The groundwater use for cultivation of other crops was only 12 (for maize) to 55 (for sugarcane) per cent of the groundwater use in paddy depending upon the crop duration and water requirement (Table 4). On an average, production of one kilogram of paddy in Punjab required 2053 litres groundwater and the estimated groundwater footprints for other crops (except cotton) were much less than for paddy. Due to substantially high groundwater use, groundwater productivity (Rs./cum) of paddy was also much lower than other crops. Technological and policy support during the green revolution period (1960s) brought a significant increase in area under paddy from 4 lakh ha during TE 1973 to 28 lakh ha during TE 2013. Presently, paddy occupies about 36 per cent of total gross cropped area and about 77 per cent of *kharif* area of the state. Thus, paddy a dominant crop in the existing cropping pattern is ecologically not suitable for Punjab and is putting groundwater resources in a jeopardy situation.

TABLE 4. CROP WISE GROUNDWATER USE IN PUNJAB IN TE 2010-11

Crops (1)	Groundwater draft (cum/ha) (2)	Crop yield (kg/ha) (3)	Groundwater footprints (Lit/kg) (4)	Crop value (Rs./ha) (5)	Groundwater productivity (Rs./cum) (6)
Paddy	12151	5918	2053	69188	5.69
Non-basmati	12127	6569	1846	67035	5.53
Basmati	12237	3440	3557	77379	6.32
Wheat	2520	4224	597	53405	21.19
Cotton	3920	2112	1856	71635	18.27
Sugarcane	6735	72906	92	155324	23.06
Maize	1485	3674	404	34306	23.10

Source: Authors' estimate based on unit-level CCS data of DES.

The promotion of basmati variety over the common paddy is often suggested as an option to reduce the groundwater demand in the light of less water requirement[2] by the former (Hindustan Times, 2014). But, the farm-level evidences showed that farmers use almost equal volume of groundwater for cultivation of basmati as well as common paddy in Punjab (Table 4). It is interesting to note that about 80 per cent of the total water requirement of paddy (including basmati) is met by groundwater even though it is grown in monsoon season. It is also indicative of the fact that Punjab farmers do not rely on the arrival of monsoon for crop cultivation. In terms of per unit production, basmati variety consumed almost double (3557 lit/kg) volume of groundwater than the common paddy (1846 lit/kg) due to substantially lower yield in TE 2010-11. However, it is interesting to note that inspite of the lower yield, large price differential made basmati variety more remunerative than the common paddy. Therefore, it is imperative to say that replacement of common paddy with basmati may improve the farmers' income but without reducing the pressure on depleting groundwater resources in the state.

A shift in the cropping pattern away from wheat-rice to a wheat-maize has been one of the suggestions to curb the groundwater depletion since the submission of Johl committee report in 1986 (Sarkar and Das, 2014). But the cropping pattern could not be altered. Again in March 2013, the government initiated crop diversification programme for diverting at least 5 per cent of area under paddy in identified over-exploited and critical blocks of Punjab, Haryana and Western Uttar Pradesh towards alternate crops (Government of India, 2013). However, under the prevailing conditions of electricity pricing and minimum support price, paddy will remain the most remunerative crop (Sarkar and Das, 2014) and farmers may not move towards diversification until incentivised by economically attractive alternatives.

Groundwater Use Efficiency in Crop Production in Punjab

The efficiency in groundwater utilisation was examined in paddy and wheat crop for which sufficient plot-wise observations are available for the period 2008-09 to 2010-11. The estimated parameters of best fitted Cobb-Douglas production function between crop yield and production inputs are presented in Table 5. All the variables except seed were found to be significantly influencing yield of paddy and wheat. The estimated coefficients represent elasticity of respective input. The groundwater

TABLE 5. ESTIMATED PARAMETERS OF COBB-DOUGLOUS PRODUCTION FUNCTION

Variable (1)	Paddy (2)	Wheat (3)
Constant	3.58***	1.65***
	(0.193)	(0.198)
Seed cost (Rs./ha)	0.010	-0.017
	(0.018)	(0.017)
Fertiliser (kg./ha)	0.066***	0.239***
	(0.018)	(0.025)
Pesticide cost (Rs./ha)	0.083***	0.043***
	(0.008)	(0.011)
Machin (hrs/ha)	0.034***	0.070***
	(0.009)	(0.016)
Labour (hrs./ha)	-0.142***	-0.023***
	(0.019)	(0.009)
Groundwater (ha-m/ha)	0.036***	0.062***
	(0.009)	(0.008)
Crop area	0.018***	0.021***
	(0.006)	(0.006)
Year_2009	-0.003	0.034***
	(0.011)	(0.012)
Year_2010	-0.083***	0.071***
	(0.012)	(0.011)
R^2	0.297	0.1910
Observations	1171	1374
Dependent variable: yield (qtl/ha)		

Note: All variables were expressed in logarithmic form.
Figures in parentheses are standard error of estimated parameters.
***, **, * significant at 1, 5 and 10 per cent level, respectively.

elasticity for paddy and wheat was 0.036 and 0.062, respectively indicating a positive marginal impact of groundwater irrigation on the crop yield. Further, the response of incremental use of groundwater was found to be much stronger in wheat than in paddy.

The groundwater elasticities were used to estimate MPP_{GW} and MVP_{GW} of groundwater (Table 6). The estimated MVP_{GW} of groundwater indicated that additional use of one ha-metre groundwater provide incremental return of Rs. 2004/- in paddy which is only 17 per cent of the incremental return in wheat. Further, the marginal return from the incremental use of groundwater in paddy was 52 per cent less than per unit groundwater cost. The principle of economic equality ($MVP_{GW}= P_{GW}$) suggests over-use of groundwater resources for paddy cultivation without adding anything to the output. As per the optimality criterion ($MPV_{GW}/P_{GW} =1$), optimum level of groundwater use for paddy cultivation should be about 52 per cent less than the present level of 1.2 ha-metre. One of the main reasons of this large scale inefficiency in groundwater use for paddy cultivation is the provision of free electricity and subsidised credit for installing and energising pumps in Punjab (Sarkar and Das, 2014).

TABLE 6. EFFICIENCY IN GROUNDWATER USE FOR CROP PRODUCTION IN PUNJAB

S.L (1)	Particulars (2)	Paddy (3)	Wheat (4)
a	Groundwater elasticity	0.036	0.062
b	Yield (qtl/ha): geometric mean	64.99	42.57
c	GW use (ha-m/ha): geometric mean	1.20	0.25
d	MPP (quintal/ha-metre)	1.95	10.56
e	Output price: (Rs./qtl)	1028	1117
f	MVP (Rs./ha-metre)	2004	11795
g	Px: Cost of water : (Rs./ha-m)	4182	4782
h	MVP/Px (<1, overuse; >1 underuse)	0.48	2.47

The subsidised credit and power for energising tubewells has not only increased the accessibility of groundwater resources but also prompted farmers to replace diesel operated pumps with the electric pumps. Notwithstanding, the share of groundwater in net irrigated area (NIA) has increased from 55 per cent to 73 per cent, while the share of electric pumps in total pump sets has increased from 47 per cent to 80 per cent during the period 1970 to 2011. Some of the possible ways to reduce excess groundwater use in paddy cultivation are, (1) increase marginal cost of water through subsidy reduction, (2) reduce dependency on groundwater by promoting integrated water resources utilisation and strictly monitoring the Punjab Preservation of Sub-Soil Water Act, 2009 which prohibits sowing paddy before May 10 and transplanting paddy before June 10, and (3) promote water saving methods of paddy cultivation such system of rice intensification (SRI), direct seeded rice, etc. Contrary to paddy, in case of wheat higher value of MVP than the per unit groundwater cost indicated suboptimal use of groundwater and wheat yield can be improved further by applying more groundwater.

Among farm-size groups, large farmers emerged as more efficient user of groundwater resources as compared to farmers with smaller land holdings. The number of irrigation hours and consequently the volume of groundwater draft for irrigating one hectare of paddy and wheat decreased with the increase in farm-size of the farmers (Table 7). Notwithstanding the inverse relationship between groundwater use and land holding size was more pronounced in paddy than in wheat. It is interesting to note that higher groundwater use on small farms could not be translated into higher crop yield. In fact the large farmers were found to be more productive in terms of crop yield during TE 2010-11.

TABLE 7. SIZE GROUP WISE GROUNDWATER USE PATTERN IN PUNJAB IN TE 2010-11

	Irrigation hours (hrs/ha)		Groundwater draft (cum/ha)		Crop yield (kg/ha)		Groundwater footprint (lit/kg)	
Size group	Paddy	Wheat	Paddy	Wheat	Paddy	Wheat	Paddy	Wheat
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Marginal	362	65	13698	2679	5640	4199	2429	638
Small	322	62	13722	2469	5719	4104	2399	602
Semi-medium	297	60	11560	2385	5885	4188	1964	570
Medium	265	59	11669	2453	5903	4231	1977	580
Large	252	57	11697	2636	6133	4321	1907	610

Note: Paddy includes both basmati and non-basmati variety

The positive relationship between farm-size and crop-yield is also reflected from the positive and significant coefficient for crop area in the regression analyses (Table 5).Thus, in the agriculturally developed state of Punjab, small farms were not found to be as productive and efficient (in groundwater use) as large farms. It could be because of high level of adoption of agricultural technology and mechanisation by the larger categories of farm households. Several studies have concluded that the advantages of smaller farms in terms of efficiency and productivity gains over the large farms cease to exist in agriculturally developed regions (Hanumantha Rao, 1975; Chadha, 1978; Ghose, 1979; Deolalikar, 1981; Subbarao, 1982; Kazi and Toufique, 2005).

V

SUMMARY AND POLICY IMPLICATIONS

The injudicious use of water resources in Punjab has resulted into the severe depletion of water table in central parts and water-logging situation in south-west region. The groundwater depletion is a negative externality due to over-dependency on groundwater as a source of irrigation for cultivating water-intensive crops particularly paddy. The time line of the existing groundwater crisis can be traced back to the introduction of paddy in Punjab as a green revolution technology backed by strong policy support of subsidised credit and electricity supply for installing and operating tubewells, and assured prices through minimum support price (MSP). Consequently, a structural shift has taken place in cropping pattern (towards paddy), irrigation source (towards groundwater) and energy source (towards electricity).

Presently, the total annual groundwater draft in the state is 14.56 BCM (72 per cent) higher than the sustainable limit of 20 BCM. Given the existing socio-economic and policy environment, such a large amount of groundwater withdrawal cannot be replenished naturally. The strategy to improve sustainability, therefore, shall include both groundwater supply augmentation and demand reduction measures. From the supply side, integrated water resources management along with the artificial recharge assumes paramount importance in augmenting groundwater resources. However, the low precipitation during the short period and insufficient non-committed surface water for artificial recharge make supply side augmentation measures inadequate. Thus, the groundwater supply augmentation efforts must be supplemented by demand reduction measures. In agriculture sector, the groundwater demand can be reduced by curtailing non-productive withdrawal as well as by improving water use efficiency in crop production.

Among other crops, paddy was found to be the most water-guzzling crop. Punjab farmer were primarily dependent on groundwater even though paddy is grown in monsoon season. The promotion of basmati variety over the common paddy is often suggested as an option to reduce the groundwater demand in the light of less water requirement. But empirical evidences indicate that replacement of common paddy with basmati may improve the farmers' income but without reducing the pressure on depleting groundwater resources in the state. Overall, paddy was found to be the ecologically misfit crop putting groundwater resources in a jeopardy situation. Moreover, there exists large scale inefficiency in use of groundwater in paddy cultivation. The optimum level of groundwater use for paddy cultivation should be about 52 per cent less than the present level of 1.2 ha-metre. Interestingly, the large farmers emerged as more efficient user of groundwater resources and productive as compared to farmers with smaller land holdings. This indicated that the usual inverse relationship between productivity and land holding size cease to exist in agriculturally advanced state of Punjab.

A shift in cropping pattern away from wheat-rice has been suggested since long but farmer may not move towards diversification until incentivised by economically attractive alternatives. Till then, the excess use of groundwater in paddy may be curtailed by, (1) increasing marginal cost of water through subsidy reduction, (2) reducing dependency on groundwater by promoting integrated water resources utilisation and strictly monitoring the Punjab Preservation of Sub-Soil Water Act, 2009, and (3) promoting water saving methods of paddy cultivation such system of rice intensification (SRI), direct seeded rice, etc.

NOTES

1. An area is said to be water-logged when the surplus water stagnates due to poor drainage or when the shallow water table rises to an extent that the soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon dioxide. As per norms of Ministry of Water Resources, an area with water table within 2 meter of the land surface is categorised as water-logged area due to rise in water table.

2. Usually, basmati paddy in Punjab is transplanted in July which coincides with the onset of the monsoon, thus requiring less groundwater than common paddy.

REFERENCES

Ballabh, Vishwa (2003), "Policies of Water Management and Sustainable Water Use", *India Journal of Agricultural Economics,* Vol.58, No.3, July-September, pp.467-476.

Central Groundwater Board (CGWB) (2013), "Master Plan for Artificial Recharge to Groundwater in India," Ministry of Water Resources, Government of India, New Delhi. http://cgwb.gov.in/documents/ MasterPlan-2013.pdf.

Central Groundwater Board (CGWB) (2014), "Dynamic Groundwater Resources of India (As on 31st March, 2011)", Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad.

Chadha, G.K. (1978), "Farm Size and Productivity Revisited – Some Notes from Recent Experience of Punjab", *Economic and Political Weekly*, *Review of Agriculture*, Vol.13, No.39, September 30, pp. A87-96.

Deolalikar (1981), "The Inverse Relationship between Productivity and Farm Size: A Test Using Regional Data from India", *American Journal of Agricultural Economics*, Vol.63, No.2, pp.275-79.

Dhawan, B.D. (1995), *Groundwater Depletion, Land Degradation, and Irrigated Agriculture in India*, Commonwealth Publishers, New Delhi.

Gandhi, V.P. and N.V. Namboodiri (2009), *Groundwater Irrigation in India: Gains, Costs and Risks*, Working Paper No.2009-03-08, Indian Institute of Management, Ahmedabad.

Ghose, A.K. (1979), "Farm Size and Land Productivity in Indian Agriculture – A Reappraisal", *Journal of Development Studies*, Vol.16, No.1, pp.27-49.

Ghosh, S.; S.K. Srivastava, A.K. Nayak, D.K. Panda, P. Nanda and A. Kumar (2014), "Why Impacts of Irrigation on Agrarian Dynamism and Livelihoods are Contrasting? Evidence from Eastern India States", *Irrigation and Drainage,* Vol.65, No.3, pp.573-583.

Government of India (2013), *Report of the High Level Expert Group on Water Logging in Punjab*, Planning Commission, New Delhi.

Government of Punjab (2012), "*Punjab at a Glance (District-wise)*", Economic Advisor to Government of Punjab, Department of Planning, Punjab.

Gupta, S. (2009), *Groundwater Management in Alluvial Areas*, Technical Paper in Special Session on Groundwater in the 5th Asian Regional Conference on INCID, December 9-11 at Vigyan Bhawan, New Delhi.

Hanumantha, Rao C.H. (1975), *Technological Change and Distribution of Gains in Indian Agriculture*, Macmillan Publisher, New Delhi.

Hindustan Times (2014), "Punjab Wants Farmers to Grow Basmati", October 2, http://www.hindustantimes.com/chandigarh/punjab-wants-farmers-to-grow-basmati/article1-1270997.aspx.

Kaur, S. and K. Vatta (2015), "Groundwater Depletion in Central Punjab: Pattern, Access and Adaptations", *Current Science*, Vol.108, No.4, pp. 485-490.

Kazi and Toufique (2005), "Farm Size and Productivity in Bangladesh Agriculture: Role of Transaction Costs in Rural Labour Markets", *Economic and Political Weekly*, Vol.40, No.10, March 5, pp.988-992.

Kulkarni, H. and M. Shah (2013), "Punjab Water Syndrome: Diagnostic and Prescriptions", *Economic and Political Weekly*, Vol.48, No.52, December 28, pp. 64-73.

Moench, Marcus H. (1992), "Chasing the Water Table: Equity and Sustainability in Groundwater Management", *Economic and Political Weekly*, Vol.27, Nos.51-52, December 19, pp.A-171-177.

Nagraj, N. and M.G. Chandrakanth (1997), "Intra and Inter Generational Equity Effects of Irrigation Well Failures", *Economic and Political Weekly*, Vol.32, No.13, March 29, pp. A-41-44.

Nawan, Nandan (2013), "Using Cost of Cultivation Survey Data: Changing Challenges for Researchers", *Economic and Political Weekly,* Vol. 48, Nos. 26 and 27, June 29, pp. 139-147.

Sarkar, A. and A. Das (2014), "Groundwater Irrigation – Electricity - Crop Diversification Nexus in Punjab: Trends, Turning Points and Policy Initiatives", *Economic and Political Weekly*, Vol.49, No.52, December 27, pp. 64-73.

Sarkar, A. (2011), "Socio-Economic Implications of Depleting Groundwater Resources in Punjab: A Comparative Analysis of Different Irrigation Systems", *Economic and Political Weekly*, Vol.46, No.7, February 12, pp.59-66.

Sekhri, S. (2013), "Sustaining Groundwater: Role of Policy Reforms in Promoting Conservation in India" in Shekhar Shah, Barry Bosworth and Arvind Panagriya (Eds.) (2013), *India Policy Forum, 2012-13, Vol. 9*, Sage Publications India Pvt. Ltd., New Delhi, pp. 149-176.

Sen, Abhijit and M.S. Bhatia (2004), "Cost of Cultivation and Farm Income", State of the Indian Farmer – A Millennium Study, Vol. 14 (New Delhi: Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, and Academic Foundation).

Shah, T.; A.D. Roy, A.S. Qureshi and J. Wang (2003), "Sustaining south-Asia's Groundwater Boom: An Overview of Issues and Evidences", *Natural Resources Forum*, Vol.27, pp.130-140.

Shah, Tushaar (1991), "Water Markets and Irrigation Development in India", *Indian Journal of Agricultural Economics*, Vol.46, No.3, July-September, pp.335-348.

Singh, K. and S. Kalra (2002), "Rice Production in Punjab: Systems, Varietal Diversity, Growth and Sustainability", *Economic and Political Weekly*, Vol.37, No.30, July 27, pp.3139-3148.

Singh, S. (2004), "Crisis and Diversification in Punjab Agriculture: Role of State and Agribusiness", *Economic and Political Weekly*, Vol. 39, No.52, December 25, pp.5583-5589.

Singh, S. (2012), "Institutional and Policy Aspects of Punjab Agriculture: A Smallholder Perspective", *Economic and Political Weekly*, Vol.47, No.4, January 28, pp.51-57.

Srivastava, S.K.; R.C. Srivastava, R.R. Sethi, A. Kumar and A.K. Nayak (2014b) "Accelerating Groundwater and Energy Use for Agricultural Growth in Odisha: Technological and Policy Issues", *Agricultural Economics Research Review*, Vol.27, No.2, pp.259-270.

Srivastava, S.K.; S. Ghosh, A. Kumar and P.S.B. Anand (2014a), "Unravelling Spatio-Temporal Pattern of Irrigation Development and Its Impact on Indian Agriculture", *Irrigation and Drainage,* Vol.63, No.1, pp.1-11.

Subbarao (1982), "Technology Gap and the Emerging Size-Productivity Relationships Following the Adoption of New Technology: An Analysis of Evidence from North-West and Eastern India", unpublished paper, Department of Agriculture and Resource Economics, University of California at Berkeley.

APPENDIX 1

SUMMARY STATISTICS OF VARIABLES FOR ESTIMATING GROUNDWATER EXTRACTION IN PUNJAB DURING TE 2010-11

Particulars (1)	Mean (2)	Minimum (3)	Maximum (4)	Standard deviation (5)
Hp : DoCP	9	2	15	1.4
Hp :EoCP	5	2	10	1.4
Hp : EoSP	10	2	20	2.6
Total head (m)	14.89	2.71	24.26	6.10
Groundwater draft (Cum/hr) : DoCP	75.28	18.50	349.13	56.94
Groundwater draft(Cum/hr) : EoCP	41.99	8.69	203.66	28.26
Groundwater draft (cum/hr) : EoSP	47.14	8.17	87.39	17.28

DoCP: Diesel operated centrifugal pumps, EoCP: Electric operated centrifugal pump, EoSP: Electric operated submersible pumps.