Paper IV-17

CHANGES IN TUBE WELLS COUNT IN TWO DECADES IN AREA UNDER CONJUNCTIVE IRRIGATION IN PAKISTAN

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ABSTRACT

A survey of tube wells was carried out in a surface hydrological unit (distributary canal command area) in Rechna Doab of the Punjab, Pakistan and results were compared with a tube well census conducted in the same area 20 years ago to update knowledge of the groundwater abstraction structures and find the changes occurring over two decades. Three water courses, located at the head, middle and tail regions of a distributary, were selected to carry out a survey of tube wells including information about ownership of each well, its installation year, bore depth, suction depth, power source, inner diameter of delivery pipe and discharge (which was determined by the trajectory method). Water table depth was collected twice from 11 hand pumps during the study (after rainy season in summer and in winter), six observation wells were also installed, two each in the command area of every sample watercourse, and monitored bi-weekly for a year. Electrical conductivity of groundwater samples collected from hand pumps, shallow and deep tube wells was also measured. Results were compared with those of Vander Velde and Johnson (1992) for the same water courses. Results show that number of tube wells increased by four and three folds in the command areas of the head and middle watercourses respectively, while the increase was 1.5 times at tail over the last two decades. Substantial increase in diesel engine and electric motor tube wells were observed while tractor driven tube wells decreased in number. Density of tube wells per 100 acres of GCA increased 4.3, 3.0 and 1.5 times in head, middle and tail regions respectively. Electric motor operated tube wells have higher discharge. Maximum average water table drop of 16.81 feet over 20 years was observed in the tail reach of the distributary canal. Shallow tube wells are disappearing from tail reach of the distributary. Most of the ground water pumped by these tube wells was of marginal quality.

INTRODUCTION

It is widely accepted that substantial increase in farmers' income due to higher crop production resulting from the increase in irrigation supplies due to installation of more than 20,000 large capacity tube wells under the Salinity Control and Reclamation Projects (SCARPs) in 1960s paved the way for the large scale development of groundwater use in the private sector in Pakistan. In order to save huge spending on the operation and maintenance of aging public SCARP tube wells the Pakistan Government shifted its policy in the early 1980s and transferred groundwater development from the public sector to the private by providing incentives and also transferring some of the existing public wells to the private sector (Johnson. 1989). Ever since the development of groundwater for irrigation is increasing through tube wells. It is either used in isolation or in conjunction with canal water (Qureshi et al., 2004).

Groundwater development through tube wells was highest in the Punjab province because it is underlain by an extensive groundwater aquifer. The Punjab is the biggest province in Pakistan in terms of agricultural production and population. In 2008-09 number of tube wells both public and private was 872444 (Agricultural Statistics of Pakistan). Besides its fruits this unregulated development of groundwater through tube wells also showed its consequences in terms of a drop in water levels and secondary salinization where low quality groundwater was used for irrigation. In a water and salt balance study in three irrigated areas in Pakistan, Kijne (1996) concluded that current irrigation and agronomic practices are not sustainable. He found mining of groundwater and continuous addition of salts due to relatively high proportions of groundwater pumped for irrigation in the sample irrigation areas of Punjab and predicted further degradation of land resources if existing high crop intensities persisted. In 1989 Vander Velde and Johnson (1992) conducted a systematic census of tube well – for the first time – with respect to surface hydrological units (i.e. distributary canal command area) in order to have a reliable, up-to-date, empirically based information database on private tube wells which was seen as prerequisite for answering questions relating to effective conjunctive management of surface and groundwater irrigation, linkages between public surface irrigation and private groundwater irrigation, distribution of the benefits of private groundwater development among different famer groups and long term sustainability of groundwater development in the Punjab. Prior to their work a number of studies on various aspects of public and private tube wells were conducted but they were either based on onetime cross-sectional interview, estimates of private tube wells drawn from civil administration or political units, that data was good enough to understand some aspects of groundwater development but not those mentioned above.

Total water available at farm gate in 2007-08 was 142.44 Million Acre Feet (MAF) of which 49.51 MAF (35%) was contributed by groundwater (Agricultural Statistics of Pakistan, 2008-09). In many areas groundwater contribution for irrigation exceeds 50%. It shows that sustainability and increase in agricultural production is linked to the sustainability of groundwater, which is not been much taken care of. Steenbergen and Oliemans (2002) summerised Govt.' policy of groundwater over last 50 years in Pakistan as supply driven with emphasis on its development and little concern about its quality deterioration and aquifer overexploitation through its regulation. Any legislation made was never enforced and ambiguity exists in the role of federal govt. and provincial government in regulating overexploitation. All policies are made and implemented from the top, federal and provincial levels with hardly any involvement of local govt. bodies and farmer originations because both are very weak in Pakistan.

In order to have a latest up to date knowledge of groundwater abstraction structures and its use and some effects on water table and quality a survey of tube wells was conducted in a surface hydrological unit (distributary canal command) in the Punjab, Pakistan in 2009 and compared with a previous study conducted in same area in 1988. Information collected may prove useful for policy makers and water managers as well as for users to work out means for sustainability of this very important water resource on which a large population depends for its livelihood.

RESEARCH SITE AND METHODOLOGY

Study was conducted in command area of Lagar Distributary which is located in Rechna Doab and originates from the Upper Gugera Branch Canal of the Lower Chenab Canal System in the Farooqabad Sub-Division of the Punjab, Pakistan (Figure 1).

Its design discharge is 38 cusecs (which equals 1.076 cubic meter per second), and the number of official outlets has increased from 30 in 1989 to 34 in 2009. Three water courses, located at the head, middle and tail regions of the distributary, were selected to conduct the survey of tube wells including information about ownership of each well, its installation year, bore depth, suction depth, power source, inner diameter of the delivery pipe and its discharge (which was determined by the trajectory method). Old/New names of selected samples water courses were 4R/10666, 11L/33032 and 21TL/62225 located at head middle and tail of distributary canal respectively. The water table depth from 6 observation wells, two each in the command area of every sample watercourse, was monitored bi-weekly form July 2008 to

November 2009, water table depth was also measured twice from 11 hand pumps in the study area . Nine farmers farm of common farm size (220 feet x 220 feet) were selected along the head, middle and tail reaches of each watercourse to find the operational hours of tube wells to provide water for the two major crops rice and wheat of two growing seasons in a year. Electrical conductivity of groundwater samples from hand pumps, shallow and deep tube wells was measured. Results were compared with those of Vander Velde and Johnson (1992) for the same water courses.

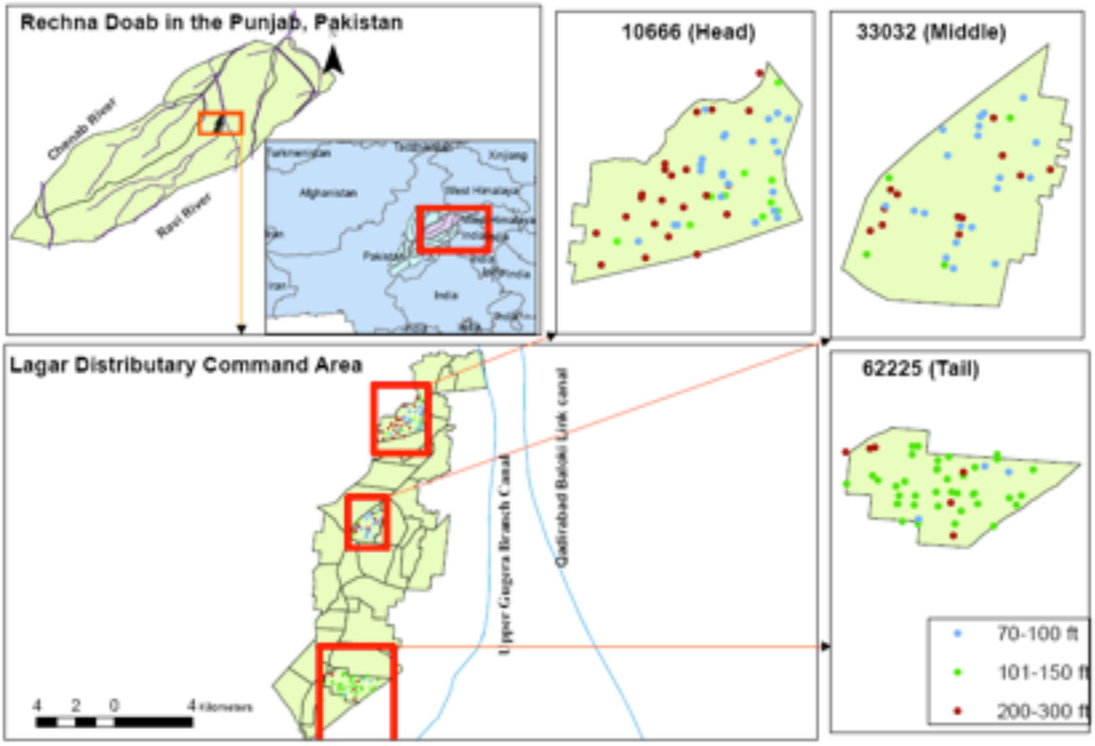


Figure 1. Map of study site and tube wells in sample water courses' command area in 2009

RESULTS

Growth in Tube wells between 1988 and 2009

Comparing the recent survey with the data from the early 1990s shows that the number of tube wells in the survey area increased dramatically. It increased by four and three folds in the command areas of the head and middle watercourses respectively, while the increase was 1.5 times at the tail over the last two decades (Table 1 and 2). The density of tube wells per 100 acres of the Gross Command Area (GCA) increased 4.3 and 3.0 and 1.5 times in the head, middle and tail regions respectively during the last two decades. In 1989 tube well densities resulted in an average one tube well for 52 and 40.14 acres on GCA and Cultivated Command Area (CCA) basis respectively in the command area of watercourse 10666. The acreage per tube well reduced to 13 and 10.03 acres for the same watercourse command in 2009. In the command area of the middle watercourse there is one tube well for 12 acres of land both on GCA and CCA basis, which was 37 acres per well in 1989. At the tail, the current average acreage per tube well is 15 which was 23 in 1989. It indicates the trend of having personal tube wells for each farmer to have maximum control on the water supply to their crops. Qureshi et.al (2003) reported an average of 29 private tube wells on an area of 640 hectares in the Punjab, which equals an area per tube well of 22 hectares. Acreage per tube observed by this study is different from Qureshi et al. (2003) due to a gap of more than 5 years between two studies and their study was on larger scale as well that may also include the saline groundwater areas and areas with different cropping systems.

Table1. Tube wells in the command area of three selected sample watercourses (1989)

Watercourse no. old/new and location	Power source			Total	Bore depth (feet)			GCA (acres)	CCA (acres)	Density (per '00)acres GCA
	Diesel	Electric	PTO		(70-100)	(101-150)	(200-300)			
4R/10666 (Head)	7	1	6	14	4	9	1	728	562	1.8
11L/33032 (Middle)	2	8	2	12	6	5	1	442	435	2.7
21TL/62225 (Tail)*	23	1	7	31	5	11	1	709	694	4.4

Source: (Vander Velde and Johnson. 1992) *Depth of 14 tube wells at tail was not given and operational were only 21 and each watercourse has a high capacity tube wells either from FAO or SCARP.

According to the farmers maximum age of a tube well using concrete assembly (pipe and screen) is 14 years, and in most of existing tube wells same assembly has been used. However, current trend is toward the PVC pipes. Quite a number of tube wells go out of operation after 7-10 years of their installation. Land around bore of such tube wells sinks 4-5 feet deep with in a radius of 8-10 feet. Farmers attribute this sinking of land to breaking of well screen pipe and removal of sediment from around the screen with pumped water. It may also be a case of land subsidence, because phenomenon is common with tube wells having higher operation hour history. Tube wells that go out of order are typically installed at new locations. Re-installation of tube wells was not traceable from the data of the survey of tube wells, therefore it became difficult to make an exact comparison of well growth over 20 years, however Figure 2 gives a picture how tube wells grew in number on the basis of information obtained from the farmers.

Table 2. Tube wells in the command area of three selected sample watercourses (2009)

Watercourse no. old/new and location	Power source			Total	Bore depth (feet)			GCA (acres)	CCA (acres)	Density (per '00)acres GCA
	Diesel	Electric	PTO		(70-100)	(101-150)	(200-300)			
4R/10666 (Head)	39	13	4	56	24	10	22	728	562	7.7
11L/33032 (Middle)	21	15	0	36	19	4	13	442	435	8.1
21TL/62225 (Tail)*	35	12	0	47	3	38	6	709	694	6.6

In the last decade of the previous century privatization of public tube wells (SCARP and FAO) took place, cheaper diesel engines came in to the market and farmers extended and intensified the cultivation of their land by shifting cropping system from less valuable crops to high value crops. Flexibility of groundwater in providing irrigation water to the farmer as per crop demand also resulted in changes in cropping system. According to the farmers a lot of area that used to be under cotton cultivation around 20 years ago has gradually turned into rice farming area.

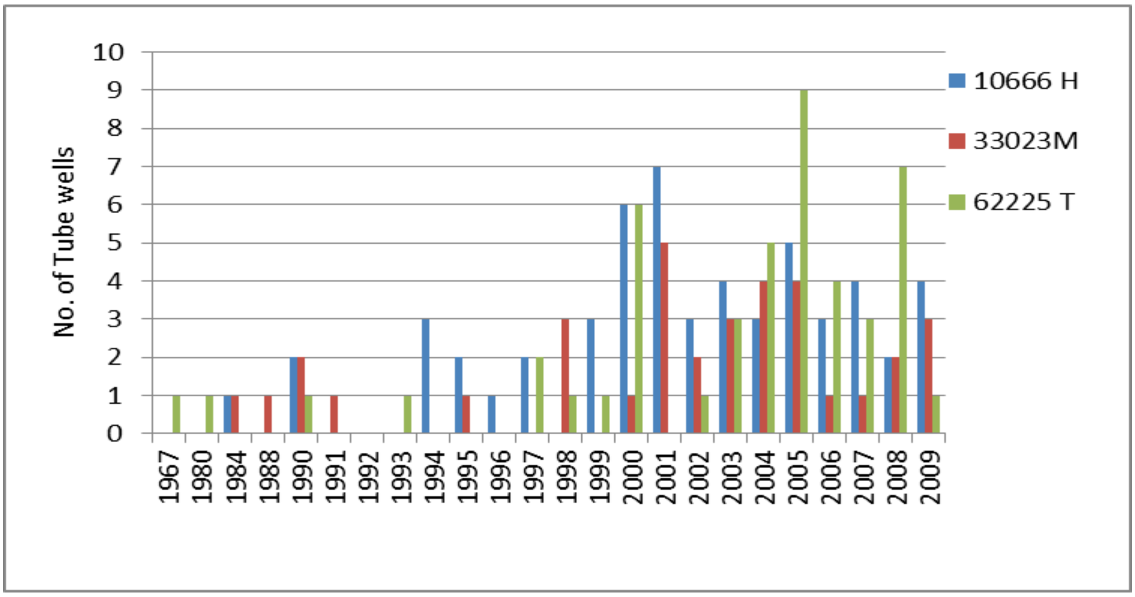


Figure 2. Tube wells growth in the study area in two decades (1989-2009)

After the transfer of the public wells to the private owners, tube wells in the private sector grew at faster rates in the last decade of the last century. Farmer desire to have full control over the irrigation supply is not letting the tube well installation process slow down.

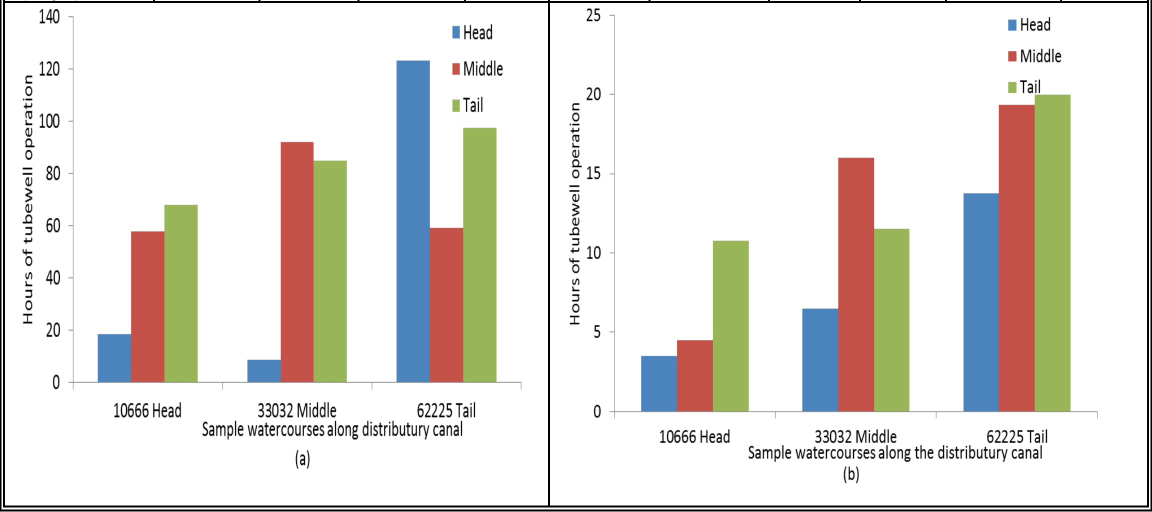
Operation of the tube wells for rice and wheat

Rice and wheat are the two major crops grown in the area in two croping seasons, Rabi (winter) and Kharif (Summer), per year. Average tube well discharges, hours of operation during wheat and rice growth periods for nine selected farms at different locations with respect to watercourses and distributary canal are given in Table 3. Dimensions of the selected farmer farms were as per dominant farm size in the study area, which was 220 feet x 220 feet, with the exception of sample farm sizes at the middle of watercourse 33032 and tail of water course 62225 which were half of the usual farm size. Tube well operation times or use of groundwater for irrigation of both rice and wheat increases as we move down from head to tail of both watercourses and the distributary canal (Figure 3). This is mainly because of decreasing surface water supply towards the downstream of the water distribution system. Water distribution along the distributary has been substantially inequitable for long times and tail outlets are typically three to six times worse off in terms of discharges than head and middle outlets (Bhutta and Vander Velde 1992; Murray-Rust and Vander Velde 1994). In the study area water users at the tail of watercourses hardly get any canal water due to seepage losses and poor watercourse conditions and mainly due to the transfer of high capacity public tube well located at the head of each water course to the private owner which used to supplement canal water and distributed among all farmers in the command area of the watercourse.

Watercourses at the extreme tail of the distributary canal receive water on rare occasions. Canal conditions and water theft from the distributary at head and tail regions was the major cause for this inequitable distribution. As canal water does not reach to the farmers at the tail of watercourses and their turns in water distribution system are still intact, so they gift these water turns to their relatives and friends in the head and middle reaches of the watercourses. Thus, due to rare availability of canal water at the tail of the distributary canal, groundwater use for both rice and wheat crop is highest. Farmers with electric motors tend to use more groundwater than those with diesel engines, probably because of higher operational cost of diesel engine operated wells.

Table 3: Spatial tube well operation hours for wheat and rice in the study area

Watercourse		10666-head			33032-middle			62225-tail		
Farm Location		Head	Middle	Tail	Head	Middle	Tail	Head	Middle	Tail
Farm Size (m^2)	Rice	4496	4496	4496	4496	2248	4496	4496	4496	2248
	Wheat	4496	4496	4496	2248	2248	4496	4496	4496	2248
Tube well discharge (cusecs)		0.72	0.93	1.29	0.89	0.73	1.02	1.44	1.16	0.41
Tube well Operation (Hours)	Rice	19	58	68	9	46	85	123	59	97
	Wheat	4	5	11	7	8	12	14	19	20
Crop duration (days)	Rice	113	104	119	102	110	124	105	98	100
	Wheat	169	160	144	166	166	165	156	159	157



Note: x-axis show three sample water courses and colour bars represents tube well operation hours at had middle and tail of each.

Figure 3. Operation of tube well to irrigate(a)rice and (b)wheat crops along distributary canal.

Type of tube wells

Substantial increases in diesel engine and electric motor driven pumps were observed while tractor driven pumps decreased in number (Figure 4a). In the command area of the head watercourse, electric motor driven tube wells increased from 7% of total in 1989 to 23% of the total in 2009. The same type of tube wells decreased from 66% to 42% in the middle and increased from 3% to 66 percent in the tail region. In case of diesel engine operated tube wells, at the head the increase was from 50% of the total in 1989 to 70% in 2009, at the middle it was from 17% to 58% while it remained constant at tail. There is no more use of tractor driven wells in middle and tail, which was 17 and 23% of the total wells in 1989; at the head it decreased from 43% of the total in 1989 to 7% of the total at present. Overall in the study area electric motor driven wells increased from 18% of the total in 1989 to 29% in 2009, diesel engine wells increased from 56% to 68% while tractor driven wells decreased from 26% to 3%. Reasons for preferences of diesel engine operated tube wells over others include low installation costs, continuous access (no power cut downs), suitability for fragmented land (mobility of diesel engines), and non-requirements of any reserved money (Qureshi et.al, 2003). Although operational cost of electric motor driven tube well is less than that of diesel tube well yet they are low in number due to high installation cost, difficult and time consuming procedure to get the approval and installation of electric supply line and above all there is a big gap between electricity demand and supply in Pakistan, which is managed by powers supply cuts for long hours. Though quite a number of farmers possess their own tractor the number of tractor operated wells have gone down, mainly due to their high operational cost.

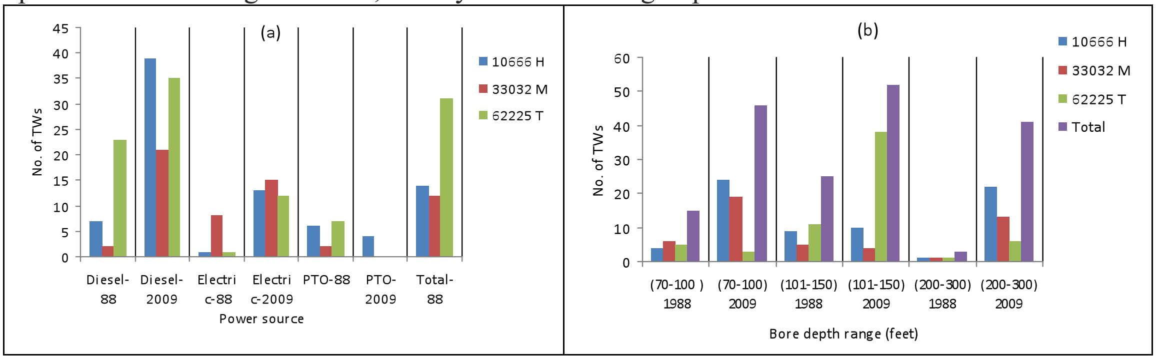


Figure 4. Types of tube wells; a) on the basis of power source, b) on the basis of bore depth

The percentage of tube wells with in bore depth ranges of 70-100 feet was 29 in 1989 at the head which has increased to 43 in 2009, in the middle it increased from 50 to 53 and at the tail it has decreased from 29 to 6 (Figure 4b). Tube wells with bore depth ranges from 101-150 feet decreased from 64% of total in 1989 to 18% of total in 2009 at the head, whereas the decrease was from 42% to 11% in the middle and an increase from 65% to 81% could be found at the tail. Wells in the bore depth range of 151-300 feet and greater increased in the command areas of all sample watercourses, the increase was from 7% of the total in 1989 to 39% at the head, while it was 8% to 36% and 6% to 13% at middle and tail respectively. Overall the tube well in the bore depth range of 70-100 feet decreased from 35% in 1989 to 33% in 2009, the decrease in the tube wells in the bore depth range of 101-150 feet was from 58% to 37% and the increase in tube wells in bore depth range of 151-300 feet was from 7% in 1989 to 30% in 2009. A water quality difference between private shallow wells and deep public tube wells, as observed by Vander Velde and Johnson (1992) could be one of the reasons for boring deep despite the significant increase in installation costs with deeper depths (Qureshi et.al, 2003).

In the 2009 survey it was found that diesel engines of five different horse power were used by the farmers. Most engines were of 16-HP followed by 18, 25, 12 and 20-HP. Engines of 12-HP were mostly used with the wells up to a bore depth of 100 feet, while other were mostly used with wells of deeper depths (Figure 5). The amount of horse powers of electric motors used by the farmers were 5, 7.5, 10 and 15. The majority of the electric motors were of 7.5 HP, followed by 10, 15 and 5-HP respectively. Electric motors of 5-HP were common with bore depths up to100 feet, the others were predominantly used with deeper bore depths. Overall, the majority of diesel engines was used with bore depths up to 150 feet while electric motors were mostly used with bore depths greater than 150 feet. Remarkable difference in discharges of tube wells of same depth and driven by engines of different horse powers were not observed. Qureshi et al. (2003) reported a mismatch between watertable depth and energy used to pump groundwater from that depth as a cause of huge energy waste. Inner diameters of the delivery pipes of the tube wells ranged from 3-inches to 6-inches. In case of diesel engines the majority (73%) of the wells have delivery piper inner diameter of 5-inches followed by 17% of 4-inches and 10% of 6-inches, while in case of electric motors 53% tube wells have delivery pipe diameters of 5-inches and 45% have diameters of 6 inches.

Tube well discharges

Table 4 gives an overview of discharges from electric motor and diesel engine operated tube wells in the study area during 1989 and 2009. In 1989 each watercourse used to have a high capacity electric tube well in the public domain installed under FAO and SCARP projects for interception of seepage from canals and vertical drainage and effluent used to supplement canal water for irrigation. In the sample watercourse 10666 the only electric tube well was from FAO and at the tail the sole electric well was from SCARP. All these tube wells no longer exist now, they have been transferred to the private sector under the SCAPP Transition Pilot Project funded by World Bank. There was no private electric well in the command area of sample head watercourse in 1989. However, discharges of the electric motor driven wells ranged between 0.92-1.37 cusecs in 2009, with an average discharge of 1.12 cusecs. The relatively high standard deviation of 0.18 cusecs in electric tube well discharges was due to use of electric power with variable horse powerage by the farmers for tube well operation. In 1989 discharges of the diesel operated wells ranged between 0.73-0.88 cusecs, those discharges were found to be in the range of 0.60-1.33 cusecs in 2009. The average discharge of the diesel operated wells in 1989 was 0.82 cusecs and 0.88 cusecs in 2009. The standard deviation of discharges of diesel wells in 2009 is higher (0.19 cusecs) compared to that of wells in 1989 (0.06 cusecs) mainly due to the higher number of wells in 2009 and more variability in horse powerage of the engines used by the farmers. Maximum and average discharges of pumps with electric motors were found to be higher than those of diesel engine operated wells in the study area in 2009.

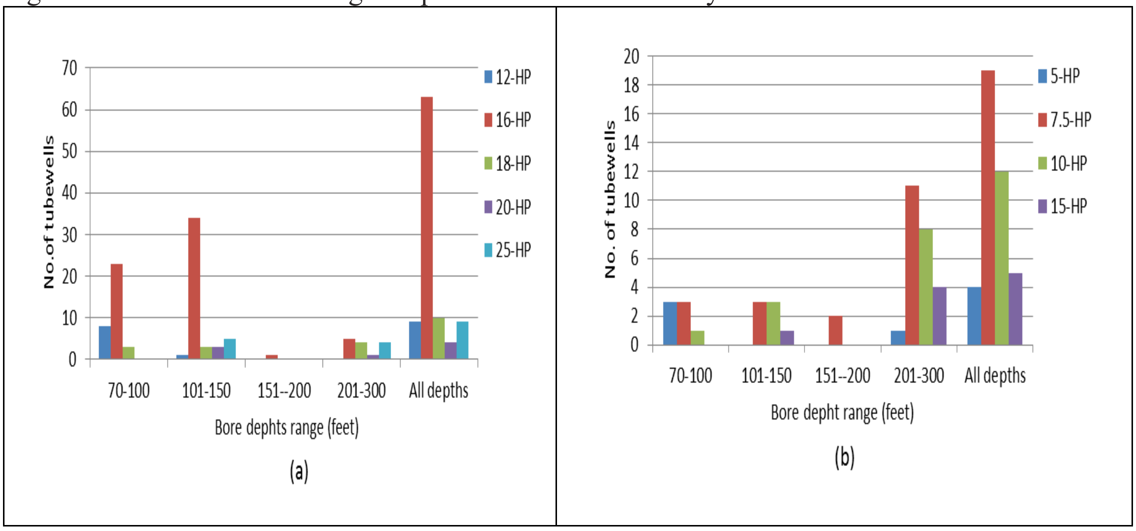


Figure 5. Horse power of diesel engines and electric motors used with tube wells of different bore depths (2009), a) Diesel engines, b) Electric motors.

Table 4. Tube well discharges during 1989* and 2009

Watercourse no.		Tube well discharge in cusecs							
		Maximum		Minimum		Average		Standard deviation	
		1989	2009	1989	2009	1989	2009	1989	2009
10666 (Head)	Electric	-	1.37	-	0.92	-	1.12	-	0.18
	Diesel	0.88	1.33	0.73	0.60	0.82	0.88	0.06	0.19
	Electric+Diesel	-	1.37	-	0.60	-	0.91	-	0.20
33032 (Middle)	Electric	1.10	1.17	0.62	0.66	0.90	0.91	0.19	0.18
	Diesel	-	1.02	-	0.64	-	0.89	-	0.11
	Electric+Diesel	1.38	1.17	0.62	0.64	0.91	0.90	0.26	0.14
62225 (Tail)	Electric	-	1.58	-	0.41	-	1.06	-	0.29
	Diesel	1.89	1.28	0.51	0.82	1.16	0.94	0.35	0.13
	Electric+Diesel		1.58		0.41		0.98		0.19
Overall	Electric	1.10	1.58	0.62	0.41	0.90	1.03	0.19	0.23
	Diesel	1.89	1.33	0.51	0.60	1.04	0.9	0.34	0.14
	Electric+Diesel	1.89	1.58	0.51	0.41	1.03	0.93	0.29	0.19

*Source for 1989 (Vander Velde and Johnson 1992)

The overall average discharge of both electric and diesel tube well in the command area of head watercourse was 0.91 cusecs with a standard deviation of 0.20 cusecs. In the command area of the sample watercourse in the middle region of study area discharges of the electric tube wells ranged between 0.62-1.17 cusecs and 0.66-1.17 cusecs in 1989 and 2009 respectively. Average discharges and standard deviations of the discharge of electric tube wells were almost the same for both the periods at this location. There were only two diesel engine operated wells at this location in 1989 and discharge of only one was available; in 2009 the discharge of the diesel engine operated wells ranged between 0.64-1.02 cusecs with an average of 0.89 cusecs and a standard deviation of 0.11 cusecs. The combined average of electric and diesel tube wells in the command area of middle watercourse was 0.90 cusecs with a standard deviation of 0.14 cusecs. As far as command area of tail watercourse is concerned there was no private electric tube well in 1989, whereas the average discharge of those in 2009 was 1.06 cusecs and their discharges ranged between 0.41-1.58 cusecs. The standard deviation of their discharges was 0.29 cusecs, this higher deviation is the result of higher variations in motor power used by the farmers.

For the diesel operated tube wells the discharges ranged between 0.51-1.89 cusecs with an average of 1.16 cusecs and a standard deviation of discharges of 0.35 cusecs in 1989. This maximum of discharge of 1.89 cusecs with a diesel engine in 1989 is exceptional as there is no information of horse power of engines in the 1989 census of tube well (Vander Velde and Johnson 1992); it may be a specific case of a high speed engine. Discharges from diesel engine operated wells in the tail region during 2009 ranged between 0.82-1.28 cusecs with average discharge and standard deviation of 0.94 and 0.13 cusecs respectively. Overall average and standard deviation of both electric and diesel operated tube wells were 0.98 and 0.19 cusecs respectively. Discharge of all electric tube wells in the command areas of the three sample watercourse in 1989 and 2009 ranged between 0.62 -1.10 cusecs and 0.41-1.58 cusecs respectively, with averages of 0.90 and 1.03 cusecs and standard deviation of 0.19 and 0.23 cusecs for the mentioned periods respectively. Cause of higher deviation in 2009 is, as said, the higher number of electric wells and variation in motor powers. In case of diesel tube wells in the command areas of all the three watercourse average discharges ranged between 0.51-1.89 cusecs in 1989 which became 0.60-1.33 cusecs in 2009; average discharges were 1.04 and 0.9 cusecs and standard deviations of discharges were 0.34 and 0.14 cusecs respectively in 1989 and 2009. Averages of the discharges from both electric and diesel engine wells in 1989 and 2009 were 1.03 and 0.93 cusecs respectively and their standard deviations were 0.29 and 0.19 cusecs.

Water table

Although these tube wells are doing a great job in draining the agricultural land by reversing the water level rising trend to declining and getting higher crop yields by supplementing canal irrigation and ultimately increasing the farm income, yet it needs to be confirmed whether this un-regulated use of groundwater is environmentally sustainable or not. Secondary salinization due to use of low quality groundwater is been reported while comparison of water tables in 1989 and 2009 shows that the resource is been over exploited. Hussain (2002) reported that farmers confirmed a fall of 0.3 m in water table in a study conducted in Rechna Doab.

Comparison of the average water tables in the command areas of the sample watercourses during 1989 and 2009 shows a drop of 2.1, 4.33 and 16.81feet in head reaches of head, middle and tail watercourses respectively. Similarly, drops in water levels at the tails reaches of the head, middle and tail watercourses were 3.83, 2.39 and 6.64 feet respectively (Table 5). Observation wells at head of head watercourse and the tail of the middle watercourse were close to the distributary canal, which may have some effect on the water levels, while the observation well at the head of the tail watercourse shows deeper water level, probably because hardly any canal water reaches this point. The tail end of this water course is close to a sanitation sump of Lagar village and it is also near the Gugera branch canal (Table 5). Shallow depth tube wells (70-80 feet) are disappearing from the command area of the tail watercourse due to water table drop.

Table 5: Comparison of water tables in study area during 1989 and 2009

Watercourse No./Location	Water table (feet)									Av. Drop in WT	
	Maximum			Minimum			Average				
	1989	2009		1989	2009		1989	2009			
		Head	Tail		Head	Tail		Head	Tail	Head	Tail
10666 Head	13.1	13.83	15.91	9.1	12.0	12.75	10.7	12.8	14.53	2.1	3.83
33032 Middle	17.5	20.5	16.91	11.5	15	14.08	13.1	17.43	15.50	4.33	2.395
62225 Tail	17.8	30.6	19.4	7.8	23	15.78	10.8	27.61	17.44	16.81	6.64

Figure 6 is a comparison of trend of the average depth to the water table in 1989 and 2009 like (Vander Velde and Johnson 1992) plotted as function of their location along the lagar canal (excluding Jhinda Minor), the general trend of decline in water levels from head to tail of the lagar command remained same as reported but water table has fallen more deeper and 2009.

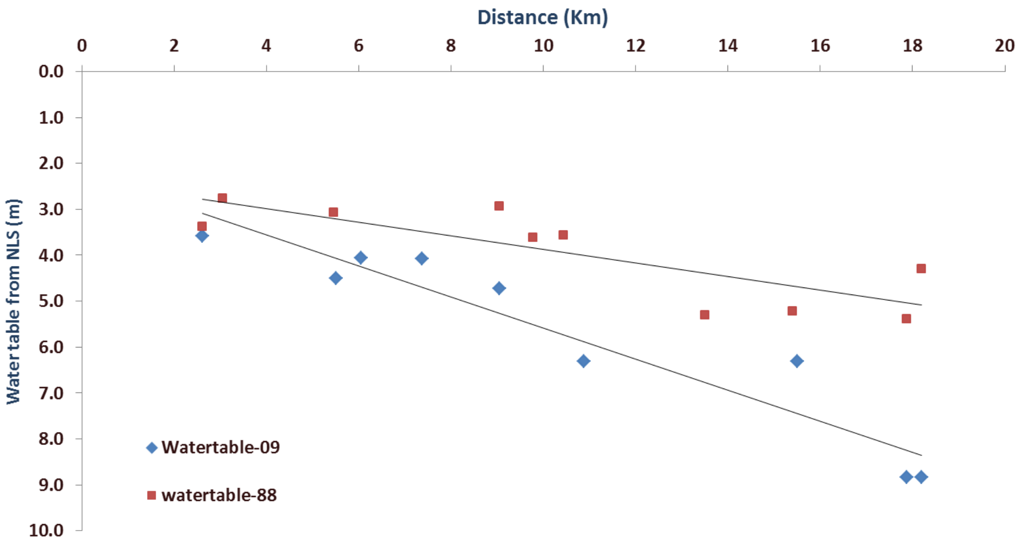


Figure 6. Water table trend along the distributary canal in 1988 and 2009

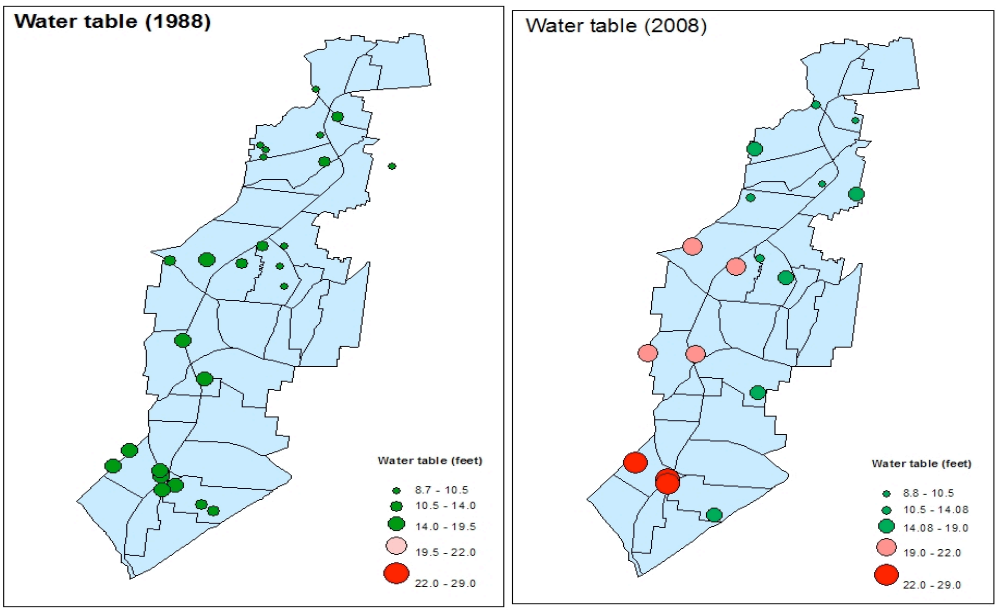


Figure 7. Water table in 1988 and 2008 in distributary command area.

Figure 7 depict gradient in water levels from head to tail of command area and left to right of the command area. Vander Velde and Johnson (1992) reported movement of groundwater from head to tail and left to right of distributary command area. More than double the pumping of groundwater compare to surface water supply for irrigation and precipitation in the area supports their finding that two big canal running north to southeast of the distributary have major contribution in groundwater recharge

Water quality

Figure 8 shows the electrical conductivity (µS/cm) of groundwater samples collected from tube wells at different locations from study area in 1988 and 2008. Mostly the groundwater in the area is of marginal quality as per standards used by Directorate of Land and Reclamation, Punjab. Samples with in fresh and Hazardous ranges were also present.

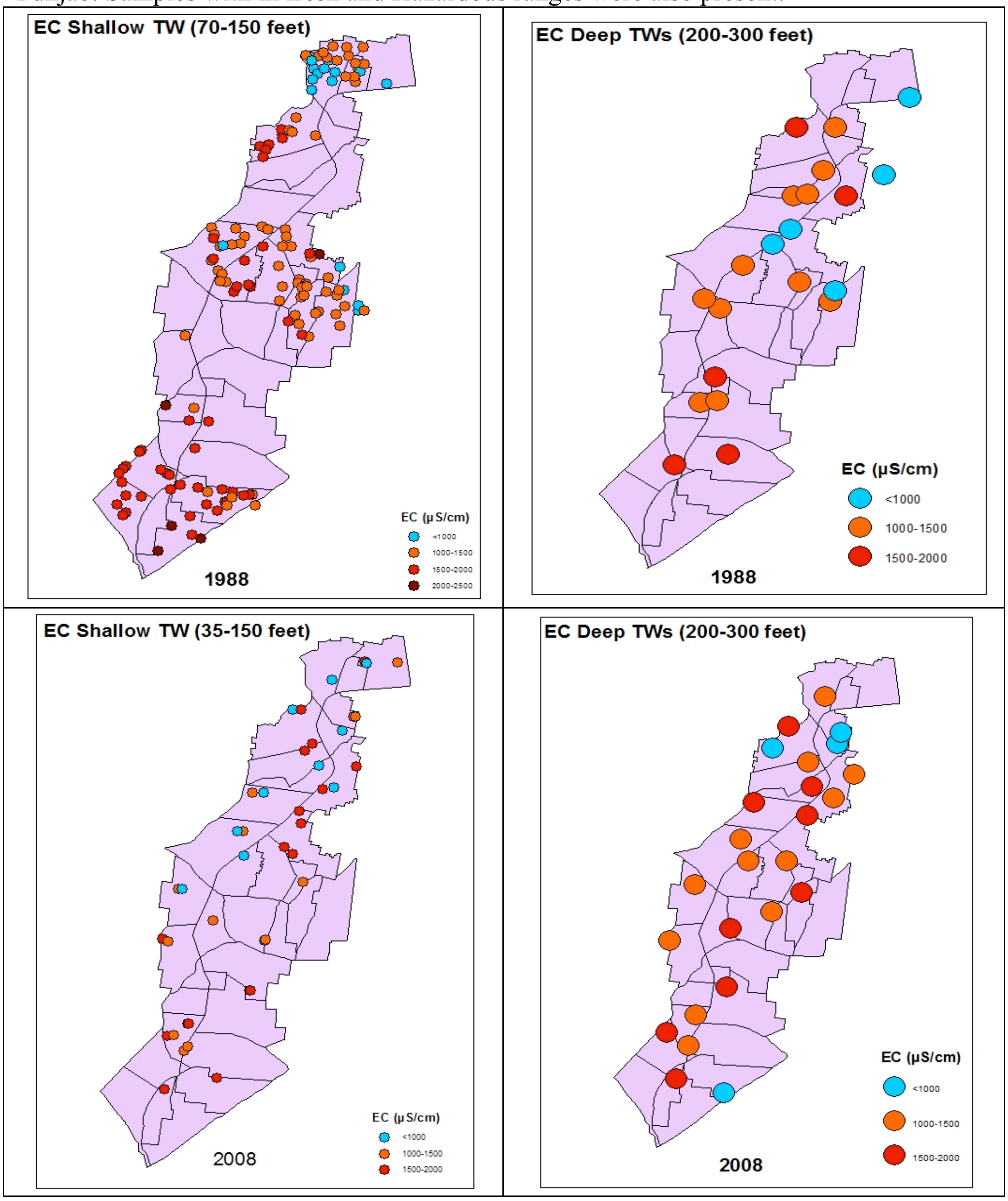


Figure 8. Ground water electrical conductivity from different depths in 1988 and 2008

Sample collected in 2008 have slightly higher EC values than those of 1988 by (Vander Velde and Johnson 1992). Number of samples collected by them was more and they also had a detailed analysis in laboratory, while just pH and EC was determined by EC meter in the later case. A detailed study can explain whether there is any intrusion from higher EC regions to lower or not. Farmer complaints of surface sealing, and appearance of white salts on dry fields and farm dykes in some areas shows that secondary salinization is occurring due to irrigation with poor quality groundwater. Some farmers also use amendments like gypsum and sulfuric acid. EC has increasing trend from head reaches to tail of the distributary canal. Murray-Rust and Vander Velde (1994) found in a study that only the top 40% of the distributary gets water of adequate quality, the next 40% get below average quality, while the tail 20% of farmers irrigate with water that is classified as saline. Asalam and Prathapar (2006) reported that land loss due to salinization is around 28,000 ha to 40,000 ha, with shallow water tables and irrigation with marginal to poor quality groundwater as causes.

DISCUSSION AND CONCLUSIONS

Tube well density increased and acreage per tube well decreased considerably over time in the study area which also had effect on cropping pattern. Increase in tube well density shows the preference of farmers to have self owned tube wells for better control over irrigation supply in time and quantity. As the development of groundwater through tube wells is still not regulated and anyone who owns a piece of land can drill a well, thus consequences of the trend (having own tube well) will further decrease spacing between tube wells in areas where land holding are small (like the study area, where already tube wells in some places are few meters apart), closely spaced tube wells owned by different farmers will in interfere in each other's pumping zones. As reliance on groundwater for crop production is very high (above 60% in study area) and groundwater depletion and quality deterioration has already started, close spacing of tube wells will result in water rights conflicts among farmers.

Groundwater use increases towards the tail reaches of both water course and distributary canal due to obvious reason of less or no canal water availability in these regions. Irrigation with marginal to poor quality groundwater without or with minimal availability of fresh canal water to leach down salts has already started process of secondary salinization, and water table falling at higher rate towards the tail reaches of distributary canal. As a result there is a decrease in shallow tube wells and increase in deep tube wells in the area, consequently both capital and operational costs of tube wells has increased in these areas. Control over water theft from distributary canal and canal water redistribution among head and tail reaches keeping in view the availability of more fresh groundwater in head reaches can be useful to reduce soil salinization in tail reaches.

Both electric and diesel tube wells has increased in the command area of sample water courses and hence same implies in the whole command area of distributary canal. Use of tractors for pumping water from tube well is becoming rare, high operational cost may be the main reason besides its unavailability due to its application in other farm activities. Diesel engine driven tube wells were highest in the area despite of their higher operational cost.

Number of tube wells in different bore depth ranges 70-100, 101-150 and 200-300 feet has increased in the command area of all sample water courses except decrease in number of tube wells in depth range of 70-100 in the command area of tail water course. Falling groundwater level in the tail region of distributary canal may be the cause.

Overall, increase in tube wells with bore depth range 200-300 feet increased to 30% of the total which was only 7% of the total in 1989, tube wells in other two depth ranges decreased as compare to their percentages of total in 1989.

Majority of diesel engines were of 16-Horse power while 7.5 Horse power motors were dominant. Delivery pipe diameter of 5-inches was common followed by 6 and 4-inches.

Maximum and average discharges of electric tube wells were higher than diesel tube wells.

Mostly the groundwater used lies in marginal to hazardous categories for irrigation. Thus posing serious threat of secondary salinization in the tail reaches of the distributary canal command.

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