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The Groundwater Economy of Pakistan

Asad Sarwar Qureshi
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International Water Management Institute

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Executive Summary

This working paper presents the results of a comprehensive groundwater survey of Pakistan, designed to understand the dynamics of groundwater use, operation and maintenance patterns, socio-economics of groundwater irrigation, land use pattern, crops, yields, and groundwater irrigation practices. For this survey, Pakistan was divided into 83 nodal intervals, with each node covering an area of 100 km*100 km; and one village from center of each grid was selected as sample. From each sample village, 15 tubewell owners were randomly selected as respondents. In total, 1200 private tubewell owners were interviewed for this study. The distance between two sample villages was kept more than 40 kilometers. This was done to avoid influences of one-village activities on the other.

The total population of private tubewells in Pakistan (Punjab, Sindh, NWFP & Balochistan) is estimated to be 629,602, with total groundwater extraction as 47.14 BCM (38.21 MAF). The survey results indicate that over the last 10 years, density of private tubewells (TWs/1000 ha) has doubled in all the four provinces of Pakistan, with Punjab taking the lead. Pakistan's groundwater economy is largely farmer-financed; some 77 percent of tubewell owners use their own funds to install private tubewells. About 10 percent of the farmers use bank loans whereas others install tubewells by sharing cost or taking loans from friends or relatives. Farmers' dependence over groundwater is not uniform across Pakistan but varies according to climatic conditions, cropping patterns and availability of surface supplies. However, with 60 percent of its farmers dependent on groundwater to meet their crop water requirement, Punjab's agriculture has become heavily groundwater-dependent. The groundwater quality also varies from place to place, fresh to extremely saline, depending on its origin, the source of recharge and the pattern of groundwater movement in the aquifer. The groundwater quality varies from 0.3-4.6 dS/m in Punjab to 0.5-7.1 in Sindh and 0.1-2.5 in NWFP.

In Pakistan, tubewells are mounted with either 12-25 horsepower diesel engine or 2-25 horsepower electrical motor and/or are operated with 50-85 horsepower tractors. The delivery pipe of private tubewells varies from 7 to 12 centimeters. There are major issues in energy efficiency. We found a large mismatch between the horsepower used and the bore depth, which is becoming a major source of energy waste. The farmers are mostly using pumps, which are not energy-efficient, mainly due to low capital investment. According to survey estimates, the total annual energy cost is Rs. 16 billion for diesel tubewells and Rs. 2.6 billion for electric tubewells. As diesel operated tubewells/wells constitute 87 percent of Pakistan's groundwater economy, improvements in the efficiency of locally made diesel tubewells can help in reducing the huge energy losses and operational costs. The average annual maintenance and repair cost of a diesel tubewell is about Rs. 7000 and for electric tubewell Rs. 4000. As a whole, farmers are spending about 4 billion rupees per year on maintenance and repair of private tubewells.

The survey results show that the distribution of the private tubewells is greatly influenced by the watertable depth. About 80 percent of the diesel-operated tubewells are installed in shallow watertable areas (6 to 12 meters), whereas electric and tractor-operated tubewells are mainly used in deep watertable areas. Installation cost of private tubewells has a direct relationship with the watertable depths. The cost of installing a tubewell in an area having watertable at or below 24 meters is seven times higher as compared to an area where watertable depth is around 6 meters. The cropping pattern of a typical private tubewell owner is wheat-cotton to wheat-rice with an average cropping intensity of

180 percent. The tubewell owners are getting about 41 percent higher wheat yield as compared to farmers depending solely on canal water.

The utilization factor of tubewells is greatly influenced by the type of tubewell, cropping patterns and agro-climatic conditions. The utilization factor of private tubewells during the Kharif season is almost double than in the Rabi season. Similarly, operational hours of electric tubewells are nearly double as compared to diesel tubewells. The selling price of groundwater from diesel tubewell is almost double than that of electric tubewell. Due to monopoly of local farmers, the groundwater selling prices in NWFP are almost double than in Punjab and Sindh provinces.

High-energy cost (increased prices of diesel and electricity) is found to be the major concern of private tubewell owners all over Pakistan. Falling watertable as a result of over pumping is considered to be the second major issue in Punjab and NWFP, whereas increasing deterioration of groundwater quality is the major concern of farmers in Sindh.

Introduction

Agriculture is the single largest sector of Pakistan's economy. It contributes about 24 percent of the Gross National Product, directly accounts for about 70 percent of the export earnings and employs more than 50 percent of its civilian labor force (PWP, 2001). Because of arid and semi-arid conditions prevailing in most parts of Pakistan, direct rainfall contributes less than 15 percent of total crop demand. Therefore, irrigated farming is the most economical and remunerative form of agriculture. Irrigated lands supply more than 90 percent of agricultural production and are major user of the water resources. The surface water resources of Pakistan are finite and the potential for increasing water supplies is limited. There is also likelihood of reduction in surface supplies through capacity losses in the reservoirs due to siltation. The difference between crop water requirements and surface supplies is met through exploitation of groundwater. Therefore, groundwater has gradually acquired a vital role in the development of agricultural and rural economy in Pakistan.

The use of groundwater for irrigated agriculture in Pakistan has a long history. In early days, the groundwater abstraction was made by means of open wells with rope and bucket, Persian wheels, karezes, reciprocating pumps and hand pumps. Large-scale pumpage and use of groundwater for irrigation started during 1960s with the launching of Salinity Control and Reclamation Projects (SCARPs). Thousands of large-capacity tubewells (0.084 to 0.14 m^3/sec) were installed to lower groundwater table and supplement irrigation supplies. This demonstration also led to a proliferation of private tubewells with a capacity of about one cusec (0.028 m^3/sec) and less by farmers in the 1970s and 1980s. Subsidized power supply and introduction of locally manufactured diesel engines provided an impetus for dramatic increase in the number of private tubewells. It is estimated that investment on the private tubewells is of the order of Rs. 25 billion whereas the annual benefits in the form of agricultural production are to the tune of Rs. 150 billion (US $ 2.5 billion) (Shah et al., 2003). The estimated number of users is over 2.5 million farmers, who exploit groundwater directly or borrow the services of their neighbors' tubewells.

The exploitation of useable groundwater provided an opportunity for the farmers of these areas to supplement their irrigation requirements and cope with the vagaries of the surface supplies. However, due to the uncontrolled and unregulated use of groundwater, problem of the overdraft of aquifers and salt-water intrusion has emerged in many areas of the Indus basin (Kijne, 1999). Excessive lowering of the watertables is making the pumping more expensive and wells are going out of production. The secondary salinization associated with the use of poor quality groundwater for irrigation has further compounded the problem. Therefore, salt-affected soils are becoming an important ecological entity in the Indus basin of Pakistan. These problems have questioned the sustainability of this resource for various uses, especially for agriculture.

The major reason for these unpleasant developments of groundwater problems is that the management of groundwater resources could not keep the pace with its development. Around the world, only few examples can be found where both demand and supply-side-interventions have been practiced. Due to many reasons, lessons regarding the management of groundwater could not be transferred wholesale to developing countries like Pakistan. Few of these reasons are listed below:

- High population density
- Exceedingly large number of groundwater users

- Low levels of resource management capacity
- 'Soft' states (political influences)
- High share of agriculture in GDP
- Wide-spread poverty and dependence of rural livelihoods on tubewell irrigation
- Poor institutional arrangements
- Lack of information on groundwater use and its socio-economic and ecological impacts

The trickiest part of managing groundwater in Pakistan lies with the large number of small-scale users involved. Over 80 percent of groundwater exploitation takes place through small capacity private tubewells. These users are neither identified, nor registered, and there is no practical way to negotiate with or set up a dialogue among so many dispersed users of the resource.

A major barrier that prevents transition from the groundwater development to management mode is lack of information. The information available on groundwater availability, quality, withdrawal and other variables is very limited or non-existent. The first step towards managing the resource is to have an idea of how much groundwater occurs and who draws how much groundwater and where. In Pakistan, different estimates exist for the total number of private tubewells (PTWs), their utilization factor and the total groundwater pumped through these tubewells. The available studies were mainly confined to specific areas with the results extrapolated to get estimation for the entire country. Therefore, the results have been treated just as an estimate, and thus, do not provide substantial basis for the planning of the resource.

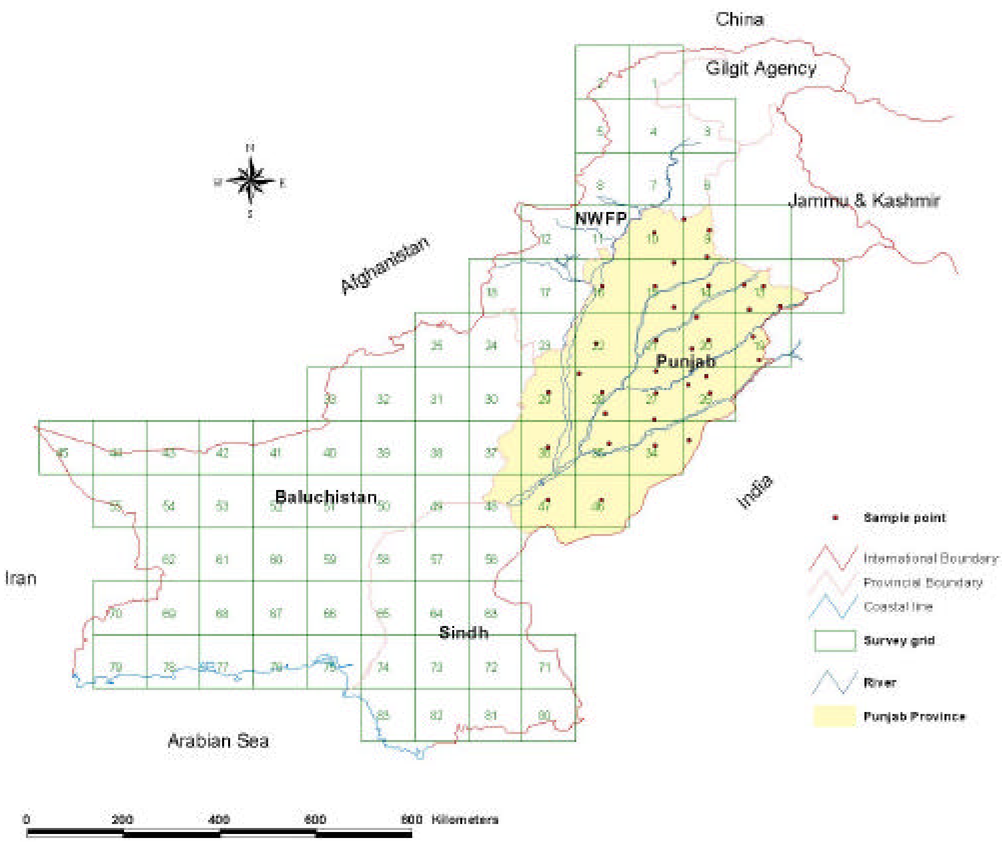
The present study was designed to do a comprehensive assessment of private tubewells, their utilization factor, and water marketing and total withdrawal for Pakistan. The study also focuses on the causes behind the increasing dependency of farmers on groundwater, possible management options and impact of groundwater use on crop yields and water productivity.

Research Methodology

For this study, Pakistan was divided into 83 unified grids. The dimension of each grid was 1^0 latitude and 1^0 longitude (100 km * 100 km). A complete grid network used for this study is shown in Figure 1. The village was taken as a basic unit for this study. One village from center of each grid was selected as a sample. From each sample village, 15 tubewell owners were randomly selected as respondents. In case there were less than 15 tubewell owners in a sample village, the data was collected from all tubewell owners of that village. The Punjab province covered 20, Sindh 14, NWFP 13 and Balochistan 36 cells of the grid system. As there was more than one district in some cells, additional villages were selected to give representation to each district of Pakistan. The administrative districts, which could not get representation through grid networking, were also studied by randomly selecting one village from each district. The distance between two sample villages was kept more than 40 kilometers. This was done to avoid influences of one-village activities on the other. In this way, 36 villages of Punjab, 21 villages of Sindh and 22 villages of NWFP were selected. Moreover from these villages, 555 tubewell owners of Punjab, 117 of Sindh and 64 of NWFP constitute the sample size for this study. Balochistan province was not surveyed due to certain security risks. Figure 1 indicates the location of sample villages in every grid and district of Pakistan.

A comprehensive questionnaire was developed to collect information regarding the profile of groundwater irrigation, critical problems faced by groundwater economy, cropping patterns, estimation of private tubewells, utilization factor and net groundwater extraction. For each sample village, information was collected at village level and also from individual tubewell owners. The village level questionnaire focused mainly on groundwater development, population, land resources and other community issues. The individual well owner questionnaire was designed to get detailed information about irrigation economy. The data collected was related to land use, crops, yields, irrigation practices, dynamics of groundwater use, operation and maintenance and associated costs and returns.

Figure 1. Grid network used for groundwater survey in Pakistan.



Results and Discussions

Private Tubewell Density

The analysis of data collected from 1200 farmers shows that over the last 10 years, growth of private tubewells has taken a quantum jump, mainly because of decreased surface water supplies and occurrence of drought conditions, especially in Punjab province of Pakistan. During the drought, the problem of groundwater depletion first led to serious drinking water problems for communities, and later, emerged as biggest challenge for agriculture. Therefore, groundwater was used as the last resort for irrigation and drinking water supplies for humans and livestock. According to Federal Bureau of Statistics, the surface water availability reduces to 26 percent during the cropping year of 2000-01 when compared with 1996. During this period, the growth of private tubewells increased by 59 percent in

Punjab province only (NESPAK/SGI, 1991). Figures 2 and 3 show that Punjab has taken the biggest lead in the development of private tubewells (Bhutta, 2002; PPSGDP, 1999; PWP, 2001; GOP, 2000; IWMI, 2002). The density of private tubewells per 1000 hectares in Punjab has increased to 46 as compared to 3 in 1965. The real jump took place over the last decade during which the tubewell density in 2002 almost doubled. This clearly demonstrates the increasing role of groundwater in the development of irrigated agriculture.

Figure 2. Historical development of tubewells in four provinces of Pakistan.

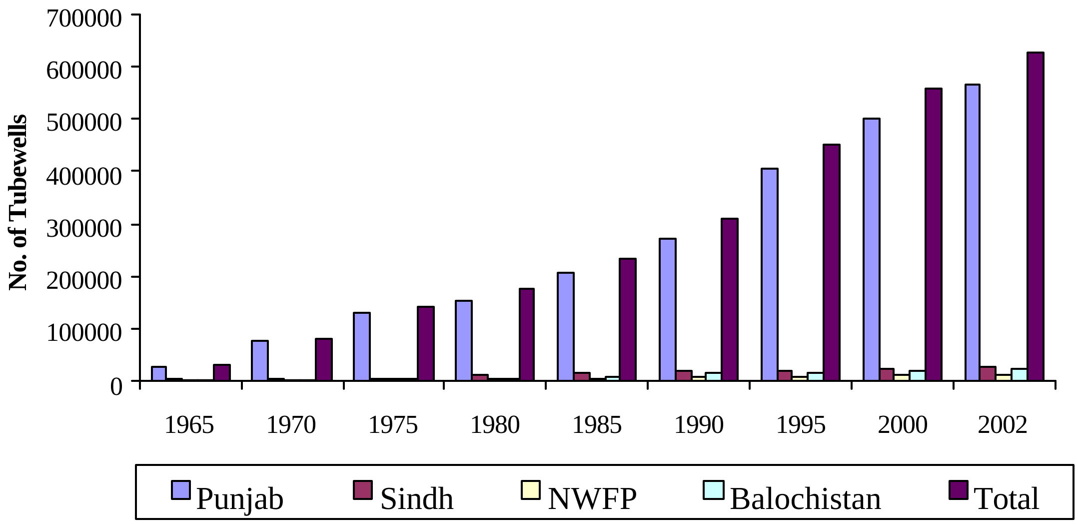
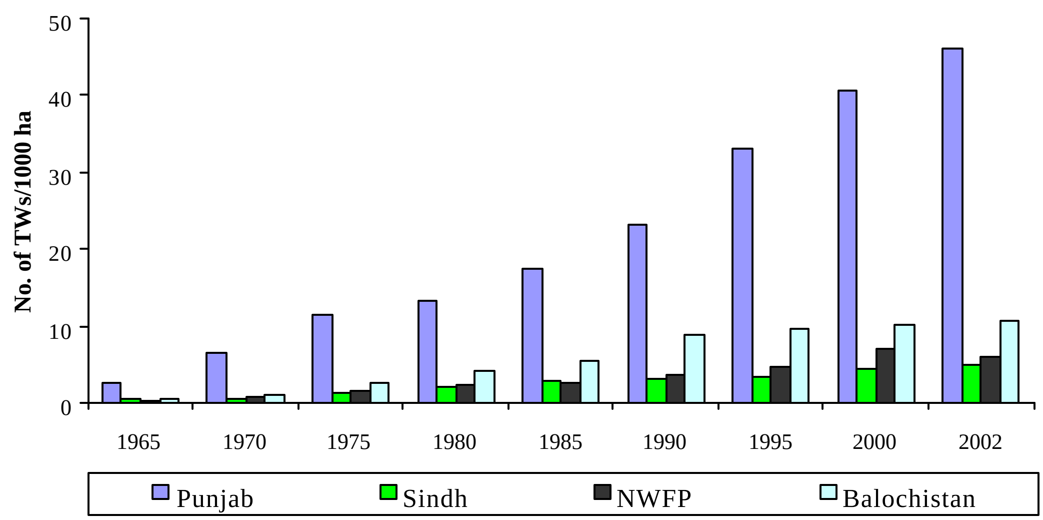
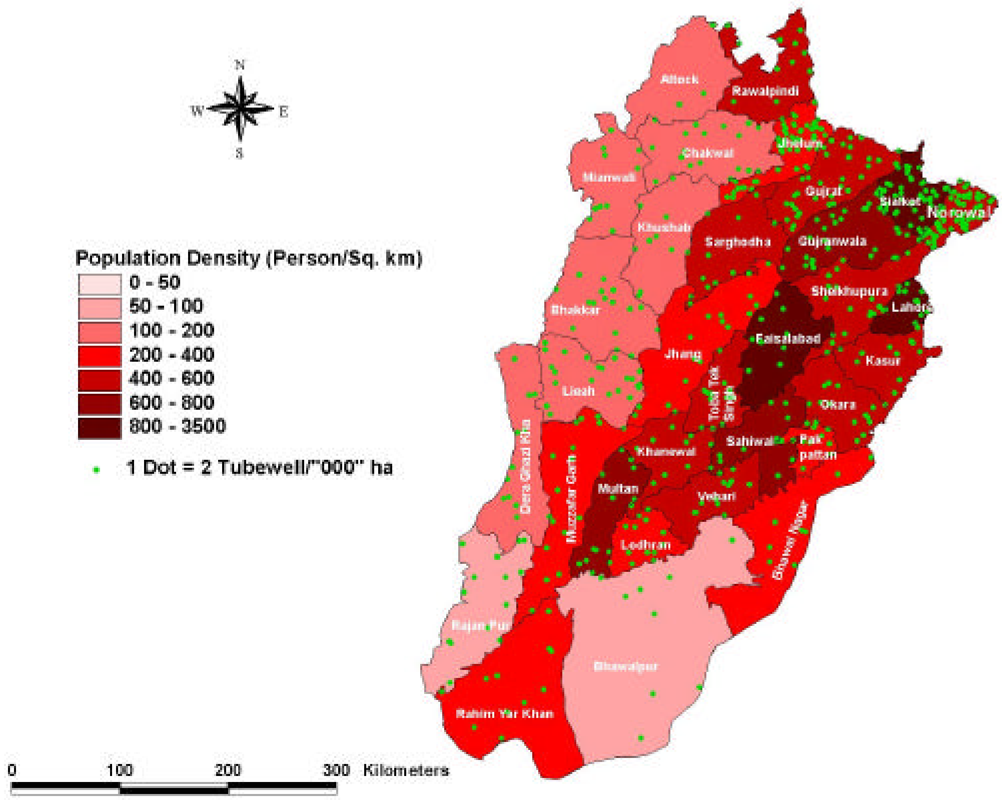


Figure 3. Increase in the density of private tubewells with time in Pakistan.



Generally, it is believed that density of private tubewells is higher in the canal command areas where farmers have installed shallow tubewells to extract the seepage from unlined canals (Bhutta, 2002). Figure 4 indicates the density of private tubewells in different districts of the Punjab province. This clearly demonstrates that the primary driver of the tubewell density is not the surface water availability or the scale of natural recharge but population density.

Figure 4. Private tubewell density in different districts of Punjab, Pakistan.



Effect of Energy Prices on Tubewell Development

During the survey, on an average, 29 sample private tubewells were found on an area of 640 hectares in Punjab, one tubewell on an area of 203 hectares in Sindh and 199 hectares in NWFP. Extrapolation of these results on the Cultivable Command Area (CCA) of Punjab, Sindh and NWFP accounts for 566,446 (90 %) private tubewells in Punjab, 28079 (4.4 %) in Sindh, 11077 (1.8 %) in NWFP during the year 2001-02. The number of private tubewells in Balochistan is reported to be 22,277 (Bhutta, 2002). The survey results are comparable to the statistics published by the Ministry of Food, Agriculture and Livestock (GOP, 2000). Category-wise detail of number of private tubewells in Pakistan is given in Table 1. Diesel tubewells (Engine as well as tractor operated) constitute about 87 percent of the total population. Rest 13 percent population is electric tubewells.

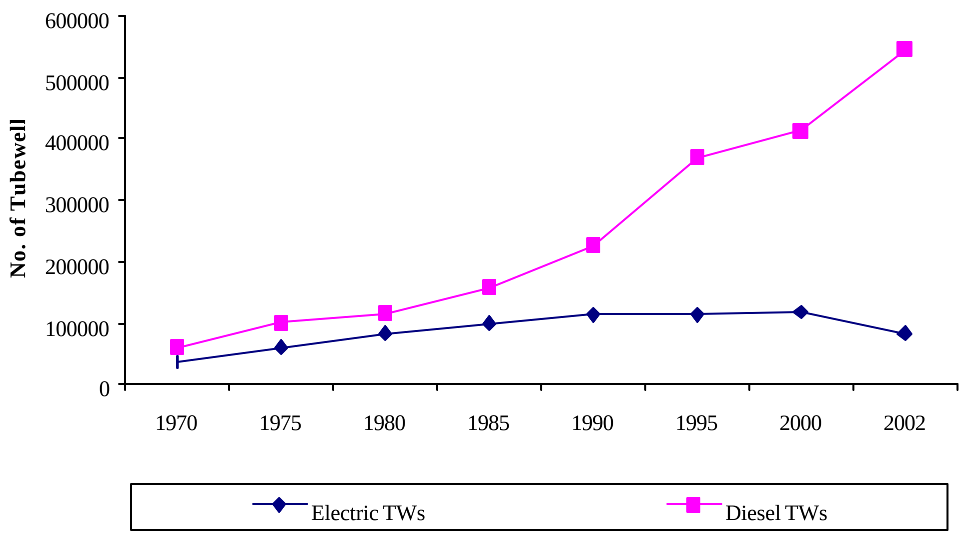
Figure 5 shows the historical development of electric[1] and diesel tubewells in Pakistan (GOP, 2000). After 1991, the trend towards installing electric tubewells began to decrease and farmers turned more and more towards the installation of diesel pumps (Figure 5). The common reasons for preferring diesel pumps 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 and Mujeeb, 2003).

[1] This electric tubewell population includes the figure of public tubewells for irrigation and drinking purposes also.

Table 1. Category-wise private tubewell population in Pakistan.

Province	Electric TWs	Diesel TWs		Total Tubewells
		Engine Operated[2]	Tractor Operated	
Punjab	65354	379728	121364	566446
Sindh	2993	25086	**[3]	28079
NWFP	5538	4209	1330	11077
Balochistan	10129	13871	**	24000
Total Tubewells	84014	422894	122694	629602

Figure 5. Temporal development of electric and diesel tubewells in Pakistan.



Most of the electric tubewells were installed in 1970s and 1980s when capital costs for the installation of electric tubewells were borne by Water and Power Development Authority (WAPDA, 1980). Uptil 1991, Pakistan had metered electricity tariff for irrigation tubewells. As the energy cost shot up, the farmers started complaining and the danger for low crop production increased as a result of non-availability of adequate water supplies. This turned the thinking of the government, and as a result, flat tariff was introduced for the irrigation tubewells. The farming community was in favor of flat tariff due to the following reasons:

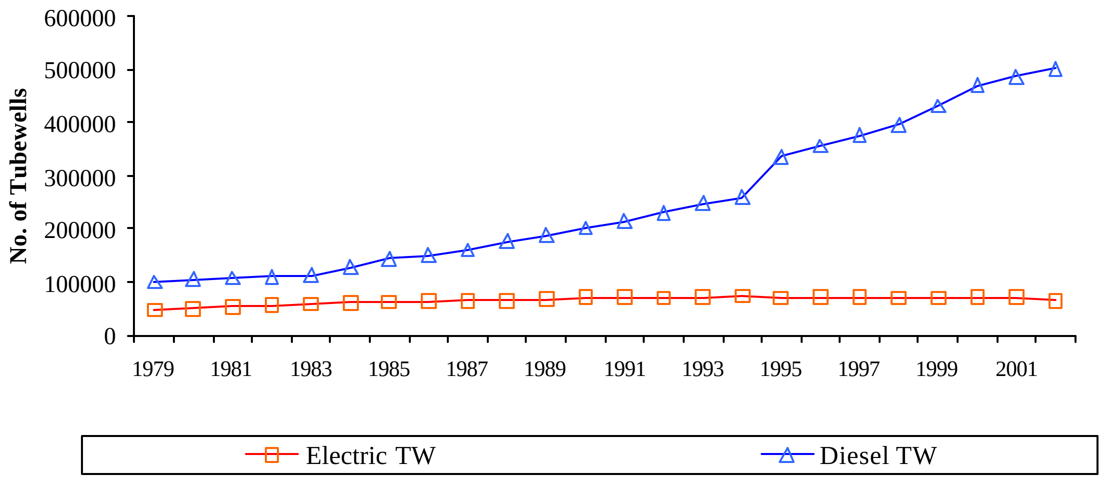
- Higher pumpage rate without the tension of billing
- Sustainability of flat tariff to farmers having large landholding
- No need of pilferage
- No need of meter tempering
- Water purchase from neighboring farmers at low rates as compared to diesel tubewell

[2] Mostly private tubewells in Pakistan use 10-24 hp diesel engines as the prime mover. These diesel engines are commonly of two types i.e., 12 - 16 hp Chinese Diesel Pumps locally called 'Peter Engine', probably after the famous brand name of a British engine manufacturer of a bygone era and 10-24 hp Slow Speed Diesel Engine locally called 'Black (Kala) Engine'

[3] Data not available.

Despite these clear advantages, the installation of electric tubewells was restricted to large landowners because the small farmers still considered it expensive or, at least, not of potential use. Therefore, they relied more on diesel tubewells, and thus, the number of diesel tubewells in the country kept on increasing. Another restricting factor in the installation of electric tubewells was the high capital cost of drawing cable from the main line to tubewell, transformer and other accessories. A farmer had to pay Rs. 25,000 for a 25 KV transformers and Rs. 10,000 per pole and additional charges for the cable. This initial investment was out of reach of many small farmers. From 1991 onwards when farmers were asked to pay these amounts, the trend towards installing electric tubewells further decreased (Qureshi et al., 2003). For example, before 1991, the ratio of electric motors to diesel pumps was 1:3 whereas it increased to 1:8 in 2000-01 in Punjab (Figure 6). This clearly shows that farmers are not interested in electric tubewells and they are fast moving towards diesel pumps in Pakistan.

Figure 6. Temporal development of electric and diesel tubewells in Punjab, Pakistan.



Mechanics of Private Tubewells

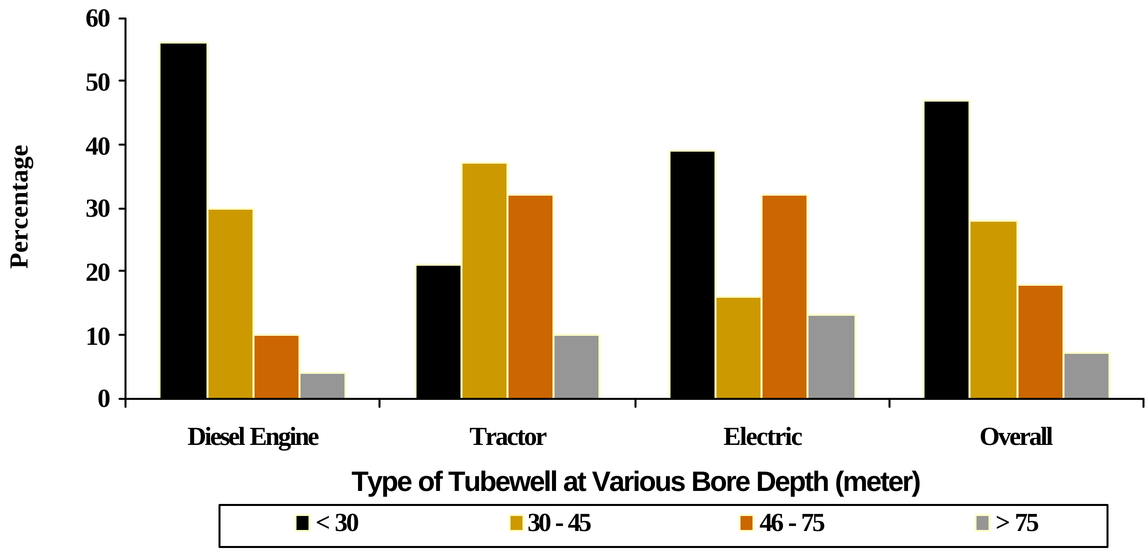
In Pakistan, there are commonly two types of wells, borehole and dug well. The borehole well is operated by electric motor, diesel engine and tractor. This type of well is commonly called *tubewell*. The other type of well, dug well, is mostly found in NWFP. The average bore depth of the tubewell and dug well is 35-85 meters, and 3-10 meters, respectively.

A typical tubewell, in Pakistan, is operated by 12-25 horsepower diesel engines, 2-25 horsepower electric motor or with 50-85 horsepower (average 50 hp) tractors. The delivery pipe of these tubewells varies from 7 to 12 centimeters. The most commonly used tractors for pumping groundwater are MF-385 (85 hp), MF-375 (78 hp), MF-240 (50 hp), FIAT-640 (65 hp), and FIAT-480 (55 hp). There is a big mismatch between the horsepower used and the bore depth of the tubewell. This mismatch is becoming a major source of energy waste. Based on survey results, the details of the borehole depth and the horsepower used in Pakistan are provided in Table 2. The horsepower used to extract groundwater from a depth of less than 15 meters, is almost equivalent to the horsepower used to draw groundwater from depths of 45-60 meters. About 75 percent of tubewells are functioning at 30-45 meters bore depth, and tractor operated tubewells at 30 to 75 meters. About 50 percent electric tubewells are operating at the depth of less than 45 meters and the rest at 46 to more than 75 meters bore depth.

Table 2. Bore depth and horsepower used to extract groundwater from various depths in Pakistan.

Bore Depth (meter)	Watertable Depth Range (meter)	Horse Power Range			Most Commonly Used Horse Power	
		Diesel TWs		Electric TWs	Diesel TWs	Electric TWs
		Engine Operated	Tractor Operated			
<15	< 3	3-16	50	2-10	12	5
15-30	3 – 5	6-22	50 - 85	5-15	12	7
30-45	5 – 12	6-24	50 - 85	2-25	12	10
45-60	12 – 18	14-25	50 - 85	2-20	16	10
60-75	> 18	16-24	50 - 85	15-25	20	15

Figure 7. Distribution of private tubewell type as influenced by borehole depth in Pakistan.



The depth to watertable is a crucial factor in the development of private tubewells. The installation cost of private tubewells has a direct relationship with the watertable depth. The installation cost of tubewell in the areas where watertable is below 24 meters is almost 7 times higher than the cost in areas where watertable depth is upto 6 meters (Figure 8). Diesel tubewells are mainly installed in shallow watertable areas (less than 6 meters to 12 meters) whereas electric and tractor operated tubewells are considered more feasible for deep watertable areas. Figure 9 gives the details of distribution of different types of private tubewells as influenced by groundwater table depth in Pakistan.

The average installation cost of diesel and tractor operated tubewell is Rs. 50,000 all over Pakistan. The average cost of electric tubewell is estimated to be about Rs. 102, 000. With increasing bore depth, the installation cost has also increased. The cost of the private tubewell installation is Rs. 338, 000 for the areas where table depth is more than 24 meters (bore depth will be more than 75 meters). During the last two decades, the installation cost of private tubewell almost doubled. Figure 10 gives the trends in drilling and machinery cost during 1975-2000.

Figure 8. Impact of groundwater table depth on installation cost of private tubewells in Pakistan.

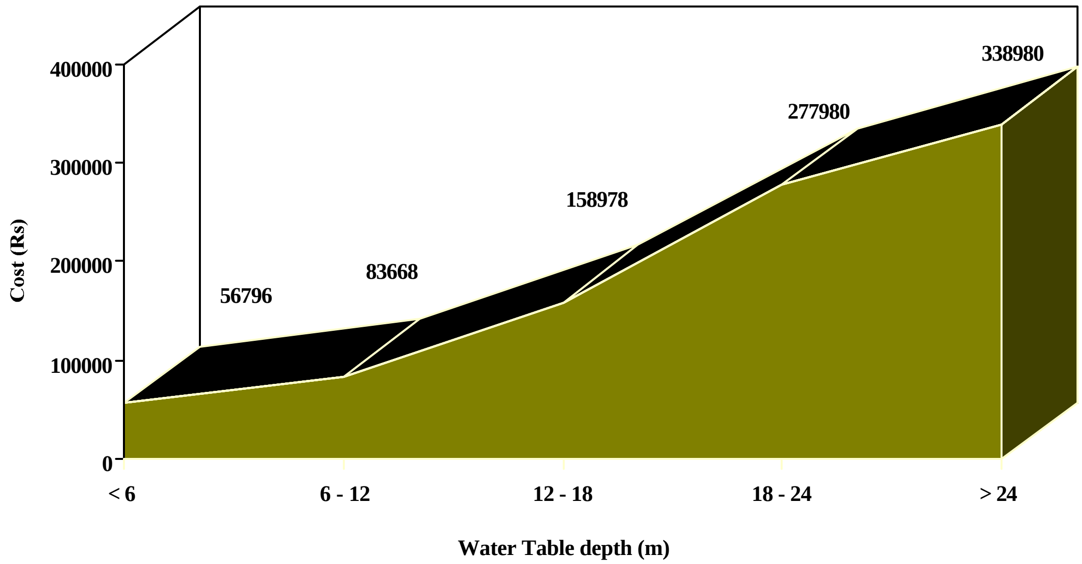


Figure 9. Distribution of different types of private tubewells as influenced by groundwater table depth (meter) in Pakistan.

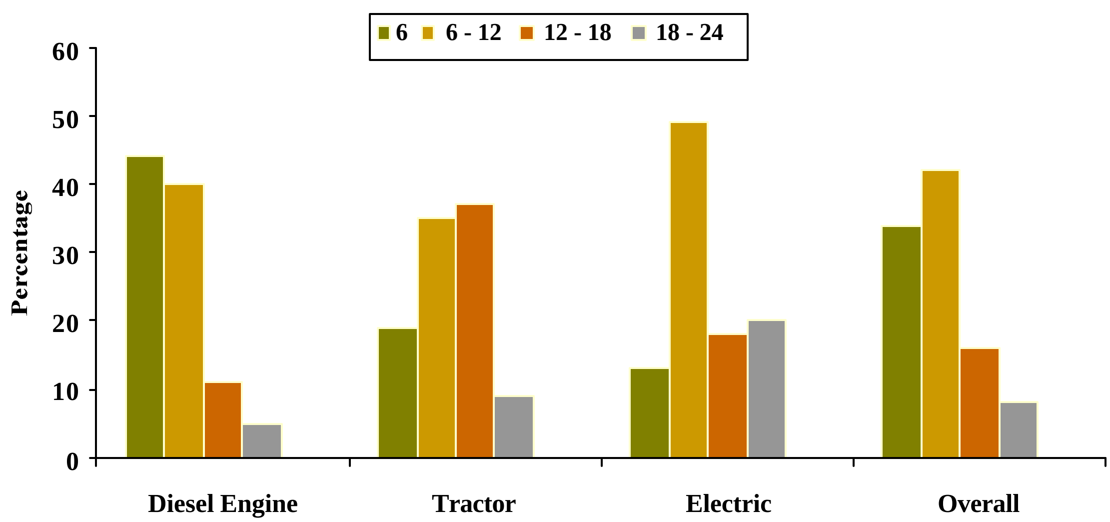
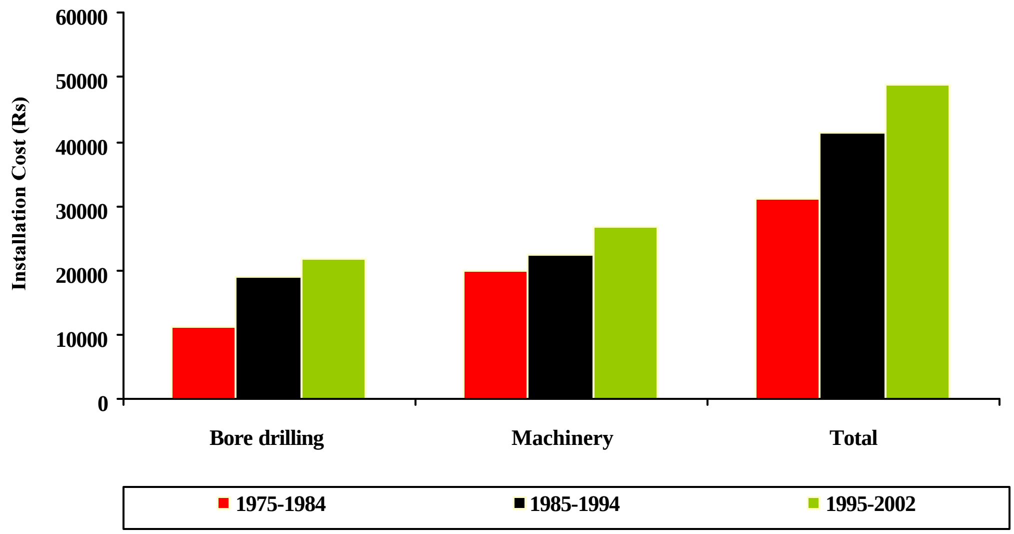


Figure 10. Historical trends in the cost of bore drilling and machinery of diesel tubewells in Pakistan.



Operation & Maintenance Patterns

According to the survey conducted, there are about 545,000 diesel and 84,000 electric tubewells in Pakistan. The fuel consumption of diesel tubewell (Chinese Pumps and Slow Speed Diesel Engine) is 1.5-2.5 liters per hour whereas tractor operated tubewells are consuming 3.5-5.0 liter per hour. The electric tubewell, on an average, are consuming about 8 units per hour with 10 horsepower motor. The overall utilization factor of diesel tubewell is 8 percent, and of electric tubewell 17 percent. With this fuel consumption of diesel tubewells, the annual fuel (diesel) consumed by the diesel tubewells in Pakistan is about 950 million liters, worth Rs. 16 billion[4]. The electric tubewells based on above mentioned power consumption are currently using 1.02 billion kilo watt-hours (kwh) costing Rs. 2.6 billion[5] annually. The total energy cost of operating these private tubewells is about Rs. 18.6 billion per annum.

The maintenance and repair of a diesel tubewell includes engine oil change, belt and pullies repair, lubrication of engine parts, engine overhauling and other mechanical repairs. In case of electric tubewells, the most common fault is motor burning due to electricity fluctuation. In Pakistan, the tubewell owners keep their tubewells in operation for long hours without considering any mechanical precautionary measures. There is also no technical guidance available to them about the efficient energy use. Most of the farmers (tubewell owners) use low quality engine oil that decreases the engine life. Engine oil is commonly changed after 100-120 hours of operation in Pakistan whereas the recommended time for the change of engine oil is every 60-80 hours after the tubewell operation (Ahmer, 2003). That is why, after two to four years of tubewell operation, diesel engine needs overhauling. The average annual cost of the maintenance and repair of the private diesel tubewell is Rs. 5000 – Rs. 8000 (average Rs. 7000), and for electric tubewell Rs. 3000 - Rs. 11000 (average Rs. 4000). The estimated maintenance cost of all diesel tubewells in Pakistan is Rs. 3.8 billion whereas for electric tubewells, it is Rs. 0.3 billion. On the whole, the farmers in Pakistan are spending about Rs. 4.1 billion per annum on these tubewells for maintenance and repair.

[4] Diesel price @Rs.17 per liter

[5] Electricity price @Rs. 3 per kwh in Punjab and Sindh and Rs. 2.45 per Kwh in NWFP and Balochistan province (GOP, 2002)

About 95 percent of the pumps are centrifugal with horizontal shaft suction lift. Submerged turbine pumps make up the remaining 5 percent. Both the diesel and electric operated pumps are of sub-standard quality and operate at sub-optimal efficiency. Often, the pumps are not designed as per appropriate feasibility. Inefficient valves and improper discharge heads are common problems. Due to high friction losses in wells and inefficient water conveyance system, energy losses are very high. Billions of kilo watt-hours of electricity and substantial quantities of diesel fuel can be saved if higher efficiency in irrigation pumps were achieved. The efficiency of the locally produced diesel pumps varies between 25 to 40 percent, whereas the efficiency of the locally produced electric powered pumps is around 50 to 80 percent (Baksh et al., 2000).

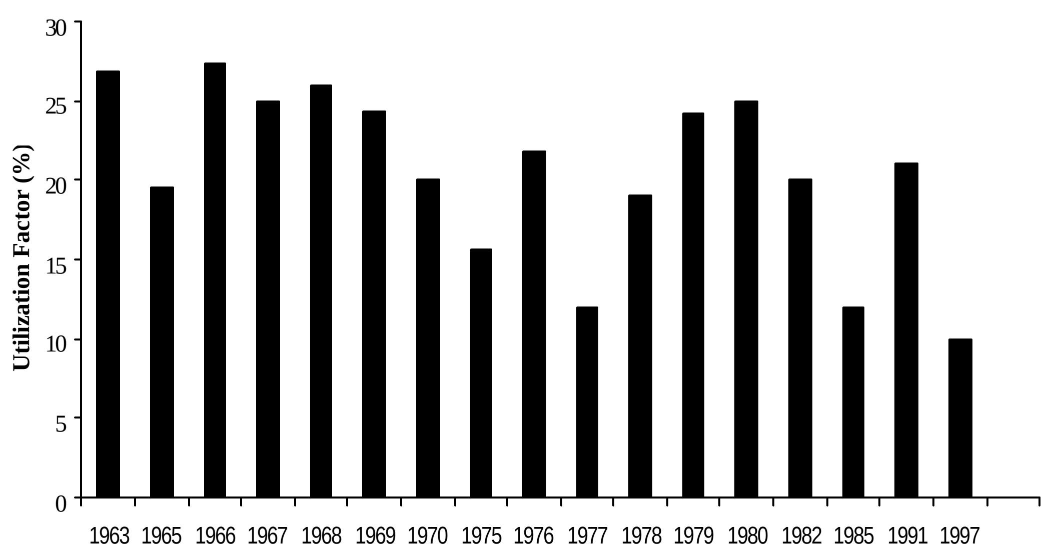
The farmers are mostly using the pumps, which are not energy-efficient mainly due to low capital investment. There is a possibility to improve water and energy efficiency of locally produced pumps by at least 50 percent i.e. from 40 to 60 percent by incorporating management and manufacturing interventions. Currently, 12-16 horsepower pumps are used in Punjab, which can be replaced by 5-12 horsepower pumps without compromising on the discharges. There is a need to develop range of pumps with 3-12 horsepower. Chinese made diesel engines are well received by the farmers due to low-fuel consumption, good discharge, and especially for the low weight (WRRI, 1998).

Utilization Factor of Private Tubewells

The utilization factor is defined as the number of tubewell operation hours in a year divided by the total number of hours in a year. The utilization factor is one of the key parameters in the estimation of the total groundwater extraction. Various organizations have estimated the utilization factor of private tubewells, as shown in Figure 11 (NESPAK/SGI, 1991). The values given in Figure 11 represents the average utilization rate regardless of the tubewell type and other factors influencing the tubewell operation.

Although differences in the values of utilization factors can be attributed to different time scales for which they were determined, still there is a consistently decreasing trend over the time. This might be due to the fact that increasing number of private tubewells reduced the dependency of farmers per unit of tubewell, which resulted in lower utilization factor.

Figure 11. Trends in the utilization factor of private tubewells in Punjab, Pakistan.



The utilization factor depends on number of factors including tubewell type, cropping season, agro-climatic zone, water markets, tariff policy, and energy prices (Qureshi and Mujeeb, 2003). Table 3 shows the effect of tubewell type and growing season on utilization factor in Punjab. There is a significant difference in the average utilization factor of different types of tubewells. The utilization factor of electric tubewells is almost double than that of the diesel tubewells. The main reason for higher utilization factor of electric tubewells is the average number of days for which tubewells operate in a season (the number of operational hours per day are almost equal for diesel and electric tubewells). The higher numbers of operating days for electric tubewells are due to the fact that each electric tubewell is serving about 20 hectares of irrigated land, which is almost double than the land irrigated by each diesel tubewell. Moreover, the sale of groundwater pumped by electric tubewells is much higher as compared to the sale of groundwater pumped by diesel tubewells.

Table 3. Utilization factor as influenced by the tubewell type and cropping season in Punjab, Pakistan.

Type of Tubewell	Average utilization factor (%)			Operating hours per day	Average days per year		
	Rabi	Kharif	Annual		Rabi	Kharif	Annual
Electric	12.46	23	17.75	7	91	138	229
Diesel (average)	4.79	8.86	6.83	6	48	72	120
Engine Operated	4.59	8.47	6.54	5	47	71	118
Tractor operated	5.47	10.10	7.79	6	50	75	125
Overall average	6.15	11.36	8.76	6	56	83	139

Among diesel tubewells, the tractor-operated tubewells have relatively higher utilization factor as compared to diesel engine operated tubewells. This is due to the fact that tractor-operated tubewells produce higher discharges and respond better to falling watertable conditions. The utilization factor also greatly varies between different growing seasons. The average utilization factor during Kharif season is nearly double than in Rabi season. During Rabi season, temperatures are moderate (less evapotranspiration), and mostly less water consuming crops are cultivated (e.g. Wheat).

The average utilization factor for diesel tubewells in Sindh is three times higher than the electric tubewells (Table 4). In Sindh, diesel tubewells are mainly used to exploit fresh shallow groundwater where electric tubewells are restricted to deep groundwater areas. As deep groundwater quality is continuously deteriorating, utilization factor for the electric tubewells is also on decline. Excessive pumping from the deep tubewells is causing up-coning problem resulting in the intrusion of saline groundwater into fresh groundwater. Due to these reasons, installation of skimming wells is becoming more popular in Sindh province. Moreover, tariff policies (especially fixed monthly cost, even in case of complete non-operation) are also discouraging farmers to use electric tubewells for the extraction of groundwater.

The average utilization factor of private tubewells in NWFP is almost double than in Punjab and Sindh. Generally, the discharges of private tubewells in NWFP are low (0.014 cumec), which force the farmers to operate the tubewells for longer hours to get the required amount of water. That is why, the utilization factor in NWFP is almost double than in Punjab and Sindh. Higher trend of selling groundwater is another factor contributing to higher utilization factor in NWFP. Table 5 illustrates that the operating hours of electric tubewells are 3 to 4 times higher than of the diesel operated wells. Diesel tubewells are mainly used to pump from dug wells or springs and are not feasible to pump water from deep rocky aquifers.

Table 4. Utilization factor as influenced by type of tubewell and cropping seasons in Sindh, Pakistan.

Type of Tubewell	Average utilization factor (%)			Operating hours per day	Average days per year		
	Rabi	Kharif	Annual		Rabi	Kharif	Annual
Electric	2.34	4.33	3.34	6	24	37	61
Diesel[6]	6.62	12.24	9.44	9	36	54	90
Overall average	6.15	11.37	8.77	9	35	52	87

Table 5. Utilization factor as influenced by type of tubewell and cropping seasons in NWFP, Pakistan.

Type of Tubewell	Average utilization factor (%)			Operating hours per day	Average days per year		
	Rabi	Kharif	Annual		Rabi	Kharif	Annual
Electric	13.11	24.21	18.67	7	80	121	201
Diesel (average)	4.67	8.63	6.65	4	54	82	136
Engine Operated	5.10	9.43	7.27	4	57	86	143
Tractor operated	3.30	6.09	4.70	4	46	69	115
Overall average	9.59	17.72	13.67	6	70	104	174

The changes in the tariff policy have made a great impact on the behaviors of irrigators, utilization factor of tubewells and groundwater markets. For example, in the Punjab province during the metered tariff period (2000-01), the average utilization factor of electric tubewells was 15.8 percent as compared to 17.6 percent during the flat tariff period. The higher utilization factor during flat tariff period was due to cultivation of high delta crops and extensive selling of tubewell water to other farmers. During the metered tariff period, utilization factor of electrical tubewells was approximately equal to diesel tubewells (15.1 percent). This shows that ele ctric tubewells were also operated according to actual water demands (Qureshi and Mujeeb, 2003).

Changes in the tariff policy for electric tubewells had a direct impact on water markets. During the flat tariff period, the cost of tubewell water was Rs. 34 per hour, which increased to Rs. 55 per hour during the metered tariff period. However, this cost was still sufficiently lower than the per hour cost of diesel tubewells (Rs. 75) during the meter tariff period. This difference in price actually prompted the farmers to buy more and more electric tubewell water, which ultimately increased the utilization factor and overall groundwater extraction through electric tubewells (Qureshi and Mujeeb, 2003).

Influence of Different Agro-climatic Zones of Punjab on Groundwater Pumpage

The extent of the use of private tubewells for irrigation depends on many factors like cropping patterns, cropping intensity, agro-climatic zones, groundwater quality and average area irrigated by tubewells. Considering variations in precipitation as the most decisive parameters, the Punjab province can be divided into three major hydrological zones. The districts of upper Punjab, where average annual rainfall is above 500 millimeters, can be characterized as high rainfall areas. The central Punjab, where average annual rainfall ranges between 300-400 millimeters, can be categorized as medium rainfall area. In the lower Punjab, the annual distribution of rainfall shows the picture of essentially an arid region, with average annual rainfall ranging between 100-150 millimeters. The cropping patterns in all these zones are very much dependent on the distribution of rainfall, availability of surface water and groundwater resources. The quality of available groundwater also plays an important role in

[6] Only petter engine diesel tubewell. No tractor operated well sample was found.

determining the extent of groundwater use for irrigation. Table 6 shows the variation in utilization factor under different agro-climatic zones.

Table 6. Variations in the utilization factor under different agro-climatic conditions.

Hydrological zones	Cropping intensity (%)	Cropping pattern	Groundwater[7] quality	Utilization factor (%)	Area irrigated by one tubewell
Upper Punjab (High rainfall)	130	Wheat-Fodder Wheat-Rice	Fit	6.80	5.8
Central Punjab (Medium rainfall)	140	Wheat-Cotton Sugarcane Wheat-Fodder	Marginally fit	5.8-12.0	14.3
Lower Punjab (Low rainfall)	150	Wheat-Cotton Sugarcane	Marginal to unfit	7.0-14.0	14.7

Table 7 shows that the rainfall distribution has a direct impact on the groundwater use. For high rainfall areas, utilization factor is relatively lower than for the low and medium rainfall areas, although rice is a major crop grown in these areas. The wide ranges of utilization factor for central and lower Punjab areas are mainly due to diversified cropping patterns. In the areas where wheat-cotton cropping rotation is more prevalent, the utilization factor is relatively low because both crops consume less water for maturity. For the areas where sugarcane and fodder crops dominate, water demand, and consequently, utilization factor is high. The average time to irrigate one hectare of land may vary according to soil type, agro-climatic conditions, leveling condition of the fields and method of irrigations. The survey data reveals that the amount of water applied to rice and sugarcane crops is almost three times (Table 7) more than the amount of water applied to wheat and cotton. This explains the higher groundwater use in the areas where rice and sugarcane crops are grown. The amount of applied water is even higher for rice crop than sugarcane, although, growing period for rice is less than half of sugarcane.

Another factor which influences the utilization factor is the average area irrigated by a single tubewell (including also the area for which water is sold). The survey results indicate that the average area irrigated by one tubewell in Punjab is about 11 hectares whereas it is 8 and 14 hectares for Sindh and NWFP, respectively. The area irrigated by a single electric tubewell (20 ha) is almost double than the area irrigated by one diesel tubewell (10 ha) in Punjab. The area irrigated by each electric tubewell is 5 and 19 hectares for Sindh and NWFP, respectively, whereas each diesel tubewell is irrigating about 7 hectares of land.

Table 7. Number of hours used to irrigate different crops in a growing season.

Crops	Hours of irrigation per season
Wheat	42
Rice	169
Cotton	55
Sugarcane	166
Fodder	77

The amount of water applied to sugarcane is on yearly basis.

[7] According to WAPDA standards (Beg and Lone, 1992), water is considered fit for irrigation if EC < 1.5 dS m^{-1}; SAR = 10 mmol L^{-1}; RSC = 2.5 meq L^{-1}, for marginally fit water, EC 1.5 - 3.0 dS m^{-1}; SAR = 10 - 18 mmol L^{-1}; RSC = 2.5 - 5 meq L^{-1} and for unfit water, EC > 3.0 dS m^{-1}; SAR > 18 mmol L^{-1}; RSC > 5 meq L^{-1}. EC is Electrical Conductivity of water, SAR is Sodium Adsorption Ratio and RSC is Residual Sodium Corbomate.

Development of groundwater has changed the cropping patterns of many areas. High delta and high value crops like rice, cotton and sugarcane have replaced traditional low value crops. Rainfall being a natural phenomenon cannot be controlled. However, shifting in cropping patterns and introduction of water efficient crops can play an important role in increasing the water productivity, reducing the groundwater use for irrigation and sustaining groundwater aquifers. The farmers having access to groundwater manage to get higher yield as compared to those who are solely dependent on canal water. The average yield of four major crops obtained with access to groundwater is shown in Table 8. Although the yields of these four major crops are lower than the potentially attainable yields, they are significantly higher than the national average yields.

Table 8. Average yields of four major crops.

Crops	No. of Irrigations	Yields (tons/ha)	National Average Yield (tons/ha)[8]	Percentage Higher than National Average
Wheat	4	3.1	2.2	41
Cotton	5	0.91	0.52	75
Sugarcane	16	50.0	47.7	5
Rice	18	3.2	1.9	68

The cropping pattern adopted by the tubewell owners is usually wheat-cotton/wheat-rice in Punjab and Sindh and wheat/vegetables in NWFP. Other minor crops are maize, sugarcane and fodder. The average cropping intensity of the private tubewell owner is about 182, 188 and 178 percent in Punjab, NWFP and Sindh, respectively. Most of the sample well owners were cultivating about two parcels of land in Punjab and Sindh, and one parcel of land in NWFP.

The water distribution system from tubewells to farmlands is very poor. About 92 percent tubewells are connected with unlined channels with an average length of 600 to 950 meters. Only 6 percent wells have lined channels with an average lined length of 180-530 meters and two percent have piped water distribution system with an average length of about 300 meters. Almost all the tubewells have closest access to the aquifer recharge sources. The most common recharge source is canal followed by river/rivulet, tanks/ponds and streams. The average distance from the closest source is 1000, 400 and 95 meters in Punjab, Sindh and NWFP, respectively.

Groundwater Pumpage from Private Tubewells

The parameters mainly used for the estimation of total groundwater extraction are total tubewell population, utilization factor and discharges. In most of the studies, groundwater pumpage has been estimated using an average utilization factor regardless of its type and location. Moreover, these studies were confined to small pilot areas and the results were extrapolated to get an overall picture for Pakistan. The survey results clearly demonstrate that the utilization factor depends on number of factors. Therefore, it is not logical to use a single value of utilization factor for the estimation of groundwater pumpage.

In this study, groundwater pumpage for each category of tubewells is calculated separately using its corresponding utilization factor. The results given in Table 9 indicate that the electric tubewells constitute only 13 percent of the total tubewell population but their share in groundwater extraction is more than 30 percent. This is mainly due to higher utilization rate because marketing of

[8] (Alam , 2001)

electric tubewell water is preferred due to lesser cost and better discharge as compared to diesel tubewells. The total groundwater pumpage in Pakistan is estimated to be 47.14 billion cubic meters (BCM) (38.21 MAF).

Table 9. Estimated groundwater pumpage for different category tubewells.

TWs Type/Province	Punjab	Sindh	NWFP	Balochistan[9]
		Electric		
Tubewell population	65354	2993	5538	10129
Utilization factor (%)	17.8	3.34	18.67	**
Discharge (cumecs)	0.036	0.037	0.026	0.008
Total Pumpage (BCM)	13.2	0.12	0.84	**
		Diesel (overall)		
Tubewell population	501092	25086	5539	13871
Utilization factor (%)	6.83	9.44	6.65	**
Discharge (cumecs)	0.028	0.027	0.016	0.008
Total Pumpage (BCM)	30.2	2.03	0.19	**
		Engine Operated		
Tubewell population	379728	25086	4209	**
Utilization factor (%)	6.54	9.44	7.27	**
Discharge (cumecs)	0.027	0.027	0.014	**
Total Pumpage (BCM)	20.9	2.03	0.14	**
		Tractor Operated		
Tubewell population	121364	**[10]	1330	**
Utilization factor (%)	7.79	**	4.7	**
Discharge (cumecs)	0.031	**	0.025	**
Total Pumpage (BCM)	9.3	**	0.05	**
		Overall		
Tubewell population	566446	28079	11077	24000
Total Pumpage (BCM)	43.4	2.15	1.03	0.56

Groundwater Quality

The quality of groundwater in the Indus basin varies from place to place, both vertically and horizontally from completely fresh to extremely saline, depending on its origin, the sources of recharge and the pattern of groundwater movement in the aquifer. Generally, the groundwater is fresh in strips along with rivers because of seepage of fresh water, but deteriorates towards centers and southwest of each Doab.

The survey results show that the groundwater quality varies from 0.3 dS/m to 4.6 dS/m in Punjab province. The water quality is fit to marginally fit for agriculture purposes in upper and central Punjab but in lower Punjab groundwater quality is almost unfit for agricultural purposes. Here, irrigation is possible only by mixing groundwater with canal water.

The groundwater quality in Sindh is usually good immediate adjacent to the river and deteriorated as we move away from the river. There is a very wide range of the groundwater quality in Sindh i.e. 0.5 dS/m to 7.1 dS/m. The native groundwater of the Lower Indus Plain is highly saline being of marine origin. Some of the saline groundwater of the region is found in the delta, where the salinity is as high as double of seawater.

[9] No survey data was available. Information based on Bhutta (2002).
[10] No sample of tractor -operated tubewells was found in Sindh province.

The quality of groundwater in the valleys, which is largely derived from infiltration of rainfall and seepage from canals and fields, is generally good (0.1 dS/m to 0.7 dS/m). However, in Banu basin, the groundwater quality of the upper horizons ranges from 0.7 dS/m to 2.5 dS/m.

In the northern regions of Balochistan, comprising Zhob, Pishin and Lora, the quality of groundwater is generally good. In the western and southwestern parts, quality of groundwater is saline to highly saline at all depths. Salinity of groundwater, sometimes, exceeds more than 5.0 dS/m such as in Nokkundi, Dalbandin, Saindak areas, Kachi plain, Nushki plain and coastal areas. The groundwater quality in the northern part of the plain is rated good (Bhutta, 2002).

The Dynamics of Groundwater Economy

The dependency of farmers on groundwater is not uniform, especially across the Punjab province, but varies according to climatic conditions, cropping patterns and availability of surface supplies. The survey results show that about 26 percent farmers in Punjab are highly dependent (more than 75 percent of total irrigation requirement comes from groundwater) on groundwater to meet crop water demands. More than 60 percent farmers in Punjab use groundwater as a supplemental source to augment canal water supplies. This clearly indicates that without groundwater availability not only Punjab but also the entire country could face serious food shortages as Punjab alone delivers more than 90 percent of total agricultural production of the country. This stresses the need for sustainable management of this resource in order to ensure food security in Pakistan.

In the central and lower Punjab areas, canal water supplies are limited and groundwater quality is only marginally fit for irrigation. Therefore, highest dependence on groundwater was found in these areas. Farmers of these areas prefer to use poor quality groundwater in conjunction with the canal water. By mixing tubewell water with the good quality canal water, farmers tend to decrease the salinity of the irrigation water in order to reduce the risk of soil salinization. Although, evidences exist that blending of saline and non-saline irrigation water is less effective in keeping soil salinity level lower than applying alternate irrigation (Hussain et al., 1990; Shalhavet, 1994; Kumar, 1995). This strategy is widely practiced in Pakistan.

The dependency on groundwater in Sindh and NWFP is only 7 percent. In Sindh province, the groundwater quality is mostly marginally fit to unfit for agricultural purposes. Therefore, the farmers are bound to rely on conjunctive use of groundwater and canal water. This is also the reason for low private tubewell development in Sindh. The situation in NWFP is reverse as the groundwater quality is excellent almost all over the province (Bhutta, 2002). But the deep watertable conditions and subsequent higher installation costs are the limiting factors for private tubewell development. For this reason, farmers prefer to use spring water and/or river water through lift pumps for drinking as well as for irrigation purposes. Moreover, the majority of the farmers in NWFP consider dug wells more appropriate and cost effective. Due to three years continuous drought, watertables have declined resulting in the drying of dug wells for most of the areas. Farmers have to deepen their dug wells to get required amount of water, which is not affordable for most of the farmers.

Tubewell owners in Pakistan operate their wells to supplement limited canal supplies, either for their own crops or the crops of other farmers who buy water form them. Water markets provide one of the most promising institutional mechanisms for increasing access to irrigation from groundwater, particularly for tenants and small farmers. In Pakistan, agriculture is heavily dependent on groundwater irrigation for crop production. Because surface canal irrigation systems do not provide farmers with adequate water or enough control over irrigation deliveries, many are turning to groundwater as a sole or supplemental source of irrigation. Sale and purchase of groundwater through informal water markets offer other farmers the opportunity to use groundwater particularly by non-owners of private tubewells. The factors affecting private tubewell development and the emergence of groundwater markets are complex and interlinked, including physical, economic and social factors (PIES, 2001).

The survey results indicate that about 30 percent well owners in Punjab and Sindh sell water from their pumps. This percentage in NWFP is only 19. The average number of buyer per seller is 3 in Punjab and Sindh and 8 in NWFP. This clearly demonstrates the demand of groundwater in NWFP. The average annual selling hours for each tubewell is 317 in Punjab, 237 in NWFP and 106 in Sindh. Similarly, average area irrigated per seller is highest in Punjab (10 ha) followed by NWFP (about 8 ha) with Sindh being the lowest (6 ha).

The most important factors involved in the cost of pumping groundwater include energy, labour and repairs. Energy cost mainly depends upon the type of tubewell, depth of pumping and size of the tubewell. The average selling rate of groundwater is given in Table 10.

Table 10. Selling rate of groundwater in different provinces of Pakistan.

Province	Selling Rate of Groundwater (US¢/m^3)[11]		
	Electric Tubewells	Diesel TWs (Diesel Engine)	Diesel TWs (Tractor operated)
Punjab	0.51-0.60	1.27-1.48	1.76-2.73
Sindh	0.78	1.22	**[12]
NWFP	0.73-0.77	2.39-4.49	3.77

The average cost of water from electric tubewells is almost half to that of the diesel engines. This is mainly due to lower operation and maintenance cost of electric tubewells. The prices of tractor-operated tubewells are higher because they consume more fuel due to greater horsepower as compared to diesel engines. Generally, tractors used for groundwater extraction have 40-85 horsepower engines whereas diesel engines are of 16-20 horsepower only. Usually, farmers prefer to buy water from tractor-operated tubewells because they have high discharges.

The selling prices of electric tubewell water in NWFP are substantially higher than in Punjab. This is mainly due to low discharges of electric tubewells. Another factor that determines the prices of groundwater in NWFP is the monopoly of the tubewell owners. Due to elevation differences in agricultural lands, farmers are bound to buy groundwater from a particular farmer who owns a tubewell in that vicinity. Tubewell owners usually take advantage of this situation and increase their charges, which farmers have to pay, as they have no other options. On the other hand in Sindh province, the main factor that determines the prices of groundwater extracted by a private tubewell is the fitness of groundwater quality for agricultural purposes.

Tubewell prices may vary within short distances; however, they remain consistent within the watercourse commands (Strosser, 1997). The factors that influence the prices of groundwater in different areas include:

1) Source of power (electric tubewell prices are low due to less O&M cost)
2) Quality of pumped groundwater that has negative impact on price
3) Tubewell discharge that determines the quantity of water pumped per hour of operation
4) Payment arrangements between buyers and sellers with spot payment being cheaper

[11] I US $ = Pak. Rs. 59
[12] Data not available

The groundwater markets are strongly established in all the three provinces. Water markets have the potential to move water from low to high value uses, promote investment in increasing the efficiency of water use and transform water from being a scarce but free resource into an economic good with an opportunity cost (Shah, 2000). From a policy standpoint, the government needs to have a better understanding of groundwater markets if it is to improve access to the groundwater resource. This requires in depth knowledge about the operation of water markets, action involved, transaction mechanism and impact of groundwater markets on agricultural productivity and farmer incomes.

Socio-economic Aspects of Well Irrigators

Problems of well irrigators

The groundwater economy depends upon a number of critical problems such as salinity, energy cost/power supply, watertable, etc. The existence of any problem may disturb the economy of the farmer as well as the province/country. Private tubewell owners of different areas are facing different problems in Pakistan. During this survey, farmers were asked to prioritize the problems regarding installation and operation of their tubewells. The results on the basis of their response are presented in Table 11. In general, high-energy cost (increased prices of diesel/electric tariffs) was found to be the major concern of farmers all over Pakistan. Electric tubewells are considered to be expensive to install as compared to diesel tubewells. However, the operational cost of electric tubewells is almost 50 percent lower than diesel tubewells. Falling watertable as a result of over pumping is considered to be the second most important issue in Punjab and NWFP. Deteriorating groundwater quality is of major concern for farmers of Sindh whereas in NWFP, high rate of failure of private tubewells is the critical problem. In NWFP, most of the groundwater is extracted through 'dugwells'. Dugwells are constructed according to the prevailing watertable conditions. Therefore, even a small decline in watertable depth is enough to abandon a 'dug well'. Due to drought conditions in the past 3-4 years, about 40 percent of dugwells were negatively affected, either they were reconstructed or just made abandoned.

Table 11. Priority-wise critical problems faced by well irrigators in Pakistan.

Critical Problems Faced by Well Irrigators	Provinces of Pakistan		
	Punjab	Sindh	NWFP
High energy cost	1	1	1
Falling watertable	2	3	2
Salinity	3	2	6
High rate of failure of wells/tubewells	4	6	3
Wells can be pumped for short time only	5	5	4
Other problems including poor water quality, expensive electric tubewell connections, etc.	6	4	7
Unreliable power supply	7	7	5

Source of Financing

Private tubewell installation depends upon the income sources of the farmers. During this survey, the sources of income for the well installation were also studied. Pakistan's rural credit markets, as in other developing countries, are characterized by the co-existence of formal, semi-formal and informal lenders. Agricultural Development Bank of Pakistan (ADBP) dominates the formal lending institutions.

Informal lenders include a wide variety of lenders in the villages and surrounding areas, friends and relatives. Semi-formal institutions are NGOs and other micro-finance institutions (say subsidy facilitators). The survey results show that about 80 percent of the farmers use their own funds for the installation of private tubewells. About 10 percent farmers acquire bank loans for the installation of tubewells. About 7.8 percent farmers in NWFP and 2.7 percent in Punjab province receive subsidy for well installation. Informal lenders (funds from other / multiple sources) are highest in Punjab followed by Sindh and NWFP.

Table 12. Source of funds used by the farmers for private tubewells installation in Pakistan.

Source of Funds	Punjab	Sindh	NWFP
Well owners who used bank loans for financing irrigation (%)	9.89	10.59	9.37
Well owners who used own funds (%)	77.2	77.65	78.13
Well owners who received subsidy (%)	2.79	Nil	7.81
Well owners who used funds from other sources (%)	1.71	5.88	3.08
Well owners using funds from multiple sources (%)	8.41	5.88	1.61

Conclusions

- The survey results indicate that the total population of private tubewells in Pakistan is 629,602. The diesel-operated tubewells/wells constitute 87 percent of Pakistan's total tubewell population. The current tubewell density in Punjab is 46 as compared to 5 in Sindh and NWFP. The density of private tubewells (TWs per 1000 ha) in Punjab is about 9 times higher than in Sindh and NWFP.
- The utilization factor of electric tubewells is almost double than the diesel tubewells. Similarly, utilization factor of all category private tubewells during Kharif season is more than double than in the Rabi season. The utilization factor of private tubewells is greatly influenced by tubewell type, growing season and agro-climatic zone. Therefore for the estimation of total groundwater pumpage, an average value of utilization factor should not be used.
- There is a big mismatch between the depth of watertable and the energy (horsepower) used to pump groundwater from this depth. This is one of the major sources of energy wastage in the agriculture sector of Pakistan. The efficiency of locally made diesel tubewells is also very low, which is not only causing serious energy losses but also increasing pumping costs. There is a possibility to improve energy efficiency of locally produced pumps by at least 50 percent, which will decrease energy bill of private tubewell owners.
- The cost of installing tubewells soar rapidly as watertable depth declines. The cost of installing tubewell in areas where watertable depth is more than 24 meters is 7 times higher as compared to those areas where watertable depth is around 6 meters. The estimated annual fuel (diesel) consumption by the diesel tubewells in Pakistan is about 950 million liters, which is worth Rs. 16 billion. The electric tubewells' power consumption is currently 1.02 billion kilo watt-hours (kwh) costing Rs. 2.6 billion annually. The total energy cost of operating private tubewells is about Rs. 18.6 billion per annum.
- The farmers with access to good quality groundwater are getting substantially higher crop yields. The yields of wheat, cotton and rice crops are 41, 75 and 68 percent higher than average national yields, respectively.

- The survey results show that the groundwater quality (dS/m) varies from 0.3- 4.6 in Punjab to 0.5 – 7.1 in Sindh and 0.1-2.5 in NWFP. The groundwater quality varies depending on its origin, the source of recharge and the pattern of groundwater movement in the aquifer.
- The selling prices of groundwater are about 50 percent higher in NWFP as compared to Punjab and Sindh. These higher prices are due to elevation differences of agricultural lands that limit the farmers to buy water from the tubewell of their vicinity. This allows the tubewell owners to monopolize the prices. However in other parts of Pakistan, the selling price of electric tubewells is almost half of diesel tubewells. This is mainly due to lower O & M costs of electric tubewells.
- High-energy costs, declining groundwater tables and incipient secondary salinization are considered to be the biggest threats to the sustainability of groundwater irrigation in Pakistan.
- The survey results indicate that Pakistan's groundwater economy is largely farmer-financed; about 77 percent tubewell owners use their own funds, 10 percent acquire bank loans and rest of the farmers depend on other sources like joint ownership, borrowing from relatives and friends and subsidy to install their private tubewells.

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