Diagnostic Analysis of Farmers' Skimming Well Technologies in the Indus Basin

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Abstract

The short canal water supply has forced the farmers to extract groundwater for irrigation purposes. Farmers are using skimming wells (both single- and multi-strainers) to supplement their canal deliveries. To ensure sustainable groundwater extraction, proper design and operational guidelines for these skimming wells are required. The starting point of such guidelines is to see the extent and existing practices of skimming well technologies. For this purpose, a field survey was conducted in the Indus Basin of Pakistan to see the farmers' groundwater extraction practices and associated problems. Participatory rural appraisal (PRA) identified several design and operational problems with farmers' skimming wells. These include; (i) depth of well, (ii) number of strainers, (iii) horizontal distance of strainers, (iv) priming, (v) water quality, (vi) sand in pumped water, and (vii) reduction in well discharge with passage of time. To investigate these problems, diagnostic analysis was carried out at the reported farmers' tubewells. A test borehole was suggested to get water quality samples along the aquifer depth. The depth of well then was decided on the basis of these water quality analyses. To decide the number of strainers, a pumping test was conducted at test borehole to estimate the contribution of individual strainer and then the numbers were increased according to the desired discharge. Similarly, placing non-return valve between blind pipe and strainer solved the priming problem. The data showed that continuous operation of a skimming well for 12 to 14 hours reduced the well discharge up to 30%. The study showed that there is an imperative needs to develop proper design and operation guidelines for skimming wells, and the farmers and local drillers are the target groups to be trained for sustainable groundwater extraction the Indus Basin of Pakistan.

INTRODUCTION

The most serious problems in the irrigated area of the Indus Basin of Pakistan are those of soil salinity and waterlogging. Salinity affects 5.8 million hectares (Mha) of land inside and outside the canal commanded area, while 9.0 Mha area has water table within 3.0 m of the soil surface (Ayers et al., 1985). Since the early sixties, Government of Pakistan has launched a series of Salinity Control and Reclamation Projects (SCARPs) to control waterlogging and soil salinity. By the mid nineties, 6.0 Mha were covered under these projects at the cost of Rs. 21 billion and these facilities were extended to another 2.0 Mha with the investment of Rs. 20 billion (NESPAK-MMI, 1995). In SCARPs, deep tubewell, surface, and sub-surface drainage systems were established. The performance evaluation of these projects revealed that some had been reasonably successful, while others failed to achieve the designed objectives (Knops, 1997). The main causes for failure were; (i) deficiencies in policy and institutional matters (Bandaragoda and Firdousi, 1992), (ii) low priority for operation and maintenance (World Bank, 1994). (iii) constraints on the public sector investment programs (Masood and Ashraf, 1997), (iv) safe disposal of saline drainage effluent (Knops, 1997), and (v) social constraints (Rafiq et al., 1997).

The SCARP tubewells served the dual purpose to lower the water table and supplement the canal water deliveries in the fresh water zones. While in the saline water zones, the tubewell water was disposed off in the surface drainage and then the drainage effluent into the nearby river. The major constraint with the SCARP tubewells in fresh water zones,was their operational inflexibility for farmers to supplement their canal supplies at irrigation turns. The SCARP tubewells are being transferred to farmers' community under new SCARP Transition Project to shift the responsibilities from public sector to private sector. Socially, the weak partnership among rural people is hindering the concept of community tubewells and farmers prefer to install their own tubewells of small capacity. These farmers' tubewells are doing what the SCARP tubewells were supposed to do in these areas.

Farmers are using skimming wells to extract upper fresh water layer for supplementing their canal irrigation deliveries and thereby achieving drainage objectives by lowering water table. Local farmers and drillers evolved skimming well technologies without any technical guidance. As a result, these wells have some economical, technical, operational management and environmental problems, which reduce the performance of these tubewells. To identify these problems, a case study was conducted in SCARP-II area in the Indus Basin of Pakistan (Figure 1).

The main objective to evaluate farmers' skimming well technologies was to have insight into their present practices, in the light of possibilities and constraints, which causes the low performance in these systems. The specific objectives of this study were, (i) to assess farmers' practices and perception to opt skimming well technologies, (ii) to document problems associated with farmers' skimming wells technologies, and (iii) to identify whether technical interventions at farmers' skimming wells would facilitate to improve the performance of these wells.

DATA COLLECTION TECHNIQUES

Participatory rural appraisal (PRA) was used to collect field data for this study. A wide range of PRA technique was used for this purpose. Before starting the detailed investigation, a preliminary survey was conducted in the study area to see the extent of skimming well technologies, its adaptability and associated constraints in different villages. The survey involved frequent field visits and open discussions with the farmers. On the basis of this survey, four villages having the highest number of skimming wells were selected for detailed investigations. The details of participatory rural appraisal techniques used in the present study are given in Table 1.

For semi-structured interviews, a questionnaire with open questions was developed. During interview, there was plenty of room for discussion with the farmers and questionnaire helped in covering all the topics. On the basis of the information collected during PRA, following problems were identified and ranked; (i) depth of well, (ii) optimal number of strainers, (iii) horizontal distance of strainers from center, (iv) priming of centrifugal pumps, (v) water quality deterioration, and (vii) reduction in well discharge with the passage of time. It was observed that farmers have their own perceptions to these problems and they have developed their own indicators to diagnose some of the problems related to their skimming wells.

SKIMMING WELL PRACTICES

Skimming well is a general term to represent any well in which the depth of the well is defined by taking into consideration the underlying saline water layer and with an intention to extract relatively fresh water. Skimming wells are partially penetrating wells and screened in the upper freshwater layer of the aquifer. Different types of skimming well are being used in the Indus Basin, including scavenger well, radial well, conventional dugwell, shallow tubewell (single strainer and centrifugal), and skimming tubewell (multi-strainer and centrifugal). In scavenger wells, two casings are lowered in either single borehole or in closely spaced boreholes. One casing is screened at the upper freshwater layer while the second is screened just above the fresh-saline interface. The freshwater and saline water are extracted separately and simultaneously. As the freshwater is extracted from the shallow well, the saline water rises in the shape of cone at the fresh-saline interface. The deep well extracts the saline water, which is raised in response to the freshwater pumping. The discharges of these wells have to fix in relative proportions so that saline water may not intrude the freshwater deliveries. This proportion is site specific and mainly depends upon the thickness of freshwater layer, aquifer parameters etc.. In scavenger wells, the disposal of saline water is a problem as well. This option to extract freshwater is being used in lower Indus Basin. The scavenger wells are technically complicated to be installed by local drillers.

Radial wells are used to extract thin freshwater layer. In these wells, perforated pipes are installed horizontally at shallow depths. In most of the cases, the intention of such installations is to lower water table. The water collected in such systems is used to supplement canal irrigation. The radial wells have high installation cost and the discharge depends upon the hydraulic head available or in other words, the depth of the pipes. The tile drains installed in drainage projects are examples of the radial wells.

The dugwells became obsolete due to revolution in pumping technology. So, shallow tubewells and skimming tubewells are most popular among farmer's community in the study area to extract shallow fresh water. The main factors contributing to their popularity among farmer's community are;(i) availability of local manufactured material, (ii) availability of local expertise for drilling, installation and maintenance, (iii) shallow water table, which helps to use centrifugal pumping units, (iv) technically simple system, as compared to deep turbines in scavenger wells, and (v) economics and affordability. In the context of this paper, the term skimming well will be used to represent both shallow and skimming tubewells collectively.

Initially, the shallow tubewells were very common in farmers' communities. The depth of shallow tubewells in the study area ranges from 12 to 67 m with diameters ranging from 12.5 to 30 cm. About 60% shallow tubewells are of 30 to 36 m deep. It consists of a borehole varying in size penetrating through the permeable layer. The upper 3 to 6 m is used as blind pipe while lower 9 to 61 m is used a strainer. The blind pipe is directly coupled with non-return valve and a centrifugal pump is used extract water (Figure 2).

Skimming tubewell consists of number of boreholes of small diameters. These boreholes are drilled around a circle at shallow depth. The number of boreholes decides the angle from the center and hence the spacing among them. The blind pipes from all the boreholes are extended through horizontal pipes toward the center of the circle. Then these pipes are joined together through a tee joint at the center. A non-return valve is attached above the tee and then a centrifugal pumping unit is mounted on the non-return valve (Figure 3). The depth of skimming tubewells in the study area ranges from 10 to 18 m with 3 to 4 m blind pipes of diameters ranging from 5 to 12.5 cm. Figures 4 and 5 show the distribution of depths in shallow and skimming tubewells in the study area.

The installation of shallow tubewell in the private sector started in 1968, after the installation of SCARP tubewells in the area. The installation of these shallow tubewells was initially in the uncommanded areas along the riverain tracts. Later, to supplement the canal water, these wells were used in the canal command areas. The PRA statistics shows that about 90% wells were installed between the middle and tail reach of the watercourse command. In study area, approximately 40% of the skimming wells were installed during last two years (1999-2000). The proportion of skimming tubewells also increased during these years. The high growth rate of skimming wells may be attributed to closure of SCARP tubewells in the area, and shortage of canal water supplies due to the present regional dry spell.

The skimming well technologies were evolved locally. With the passage of time, local drillers and farmers have developed expertise on the installation of skimming wells and they are trained enough to diagnose and solve, to some extent, problems related to their tubewells. The issues like depth of well, number of strainers, horizontal distances of strainers, priming, water quality, sand in pumped water and reduction in skimming well discharge with the passage of time need to be refined to make the system more efficient and cost effective.

Diagnostic Analysis of Skimming Well Problems

The most reported problems during PRA were analyzed at farmers skimming wells. Local farmers were involved in the learning process. A rational and progressive diagnostic approach was adopted to enhance the farmers understanding regarding the problems with their skimming wells. The reasons of successes and failures were discussed with them. The main objective of this approach was that the farmers must own the outcomes of these diagnostic analyses.

Depth of Well

The depth of the skimming well mainly depends upon the required discharge of the well and the local hydro-geological condition of the aquifer. The depth of well is directly related to the cost of the skimming well. The discharge of the skimming wells in the study area ranges from 23 to 30 liters per second. It can be reasonably assumed from the data that farmers' target discharge is approximately 28 liters per second. It can be achieved either by drilling a single borehole in thick freshwater layer as in shallow tubewells or by using more than one borehole in relatively thin freshwater layer as in skimming tubewells. In both the cases, the depth is very important as the water quality deteriorate along the aquifer profile. The PRA showed that most of the farmers depend upon local drillers regarding the depth of skimming wells and other design parameters. When field team consulted the local drillers to know the bases of their decision regarding the depth of wells, the drillers told that the farmers are only interested in high discharge and always demand a delivery pipe full of water. In this situation, the driller use a high factor of safety by drilling deep wells and hence maintain their business repute at the cost of farmers money. Most of the drillers are also suppliers of the skimming well material and have their vested interest in quantity of material.

During diagnostic analysis, an innovative method was adopted in the field, in which a test borehole of small diameter was drilled. The water samples from the bailer at different depths were collected during drilling and these were analyzed for water quality. The result of water quality analysis helped in determining the depth of the skimming wells. The strainer was lowered up to the depth where the quality is good or marginal. Table 2 showed the result of water quality along the depth during a field trial. The water quality started deteriorating below 18 m. The electric conductivity (EC) of less than 1.50 dS/m is considered good for irrigation (Qureshi and Barrett-Lennard, 1998) and this was available at depth less than 18 m. Hence, it was decided to keep the depth of the well above 18 m.

With this method of water sampling, one cannot get samples those are true representative of the water quality at that profile. The samples collected from bailer are mixed water from different geological profile. But in the present context, the interest was to find out the expected quality of the pumped water, which also comes from a long geological formation and hence, the method adopted in the field served the purpose.

Number of Strainers

The number of strainers in the study area varies from 1 to 26 but 10 and 18 strainers were common (Figure 6). Farmers' decision regarding the number of strainers in skimming tubewells is arbitrary. The farmers do not have any idea about the optimal number of strainers. In most of the cases, they have to depend on the local drillers who decide the number of strainers. Sometimes, farmers follow the neighboring well design taking into consideration the quantity and quality of water from that tubewell.

Most of the farmers and drillers have this misapprehension that the discharge of well will increase with the number of strainers. Theoretically, this is true but up to a certain number. The farmers also prefer to install more number of strainers with the intention that if some strainers have to be closed due to one or the other reasons, the remaining strainers will be functional without reducing discharge significantly. There is general consensus among farmer's community that skimming tubewells are more vulnerable to get any sort of operational problem due to higher number of strainers. The size of strainer (diameter and length) also varies widely for the same depth of the skimming wells. Tables 3 and 4 show how the strainer diameter and length change with depth of the shallow and skimming tubewells, respectively.

Keeping in view the framer's target discharge (i.e. 28 liters per second), the test borehole described above was then converted into one of the well point with 9 m strainer and 9 m blind pipe of 7.5 cm diameter. A pumping test was performed at this borehole to the see the contribution of individual strainer. The discharge from this single-strainer was about 6.5 liters per second. So it was decided to drill three more boreholes of the same specifications to get the target discharge. This 4-strainers skimming tubewell has discharge of 26 liters per second.

Horizontal Distances of Strainers

It is a common practice among farmer's community to install the strainers in skimming tubewells at the same depth but at varying distances from the pump. In farmers' perception, if the strainers are installed at the same horizontal distances, they will share the water of each other thereby reducing the overall discharge of the skimming well. In some cases, it is observed that farmers try to install the well near the watercourse to facilitate the diversion of water and hence install boreholes of that side at shorter distance from the center. Figure 7 shows the arrangement of horizontal distances in 16-strainers skimming tubewell in the study area.

The proper horizontal distances of the strainers depend upon the allowance, which the designer provides to allow the drawdown to overlap. Different field trials are being conducted in the field with different scenarios to see the effect of variation of horizontal distances of strainers on the well discharge and hence to find the optimal distance of strainer from the center. The objective would be to spatially distribute the pumping stress so that saline water cone would not arise under any of the borehole. The results of these trials will be presented elsewhere.

Priming

The priming has been a major problem of a centrifugal pump and shallow and skimming tubewells in the study area are not exemption. During PRA, most of the farmers (about 62%) reported that they are facing the problem of priming in their skimming wells. This problem is more pronounced in skimming tubewells as compared to shallow tubewells. The PRA statistics shows that 75% of the total skimming well owners are facing problem of priming. During field visits, it is observed that the time taken to lift water in shallow tubewells varied from 5 to 20 minutes while in skimming tubewells it is from 10 to 40 minutes.

It was observed that farmers in the study area are not following the conventional well design. In the conventional well design, the non-return valve is fixed at the lower end of the suction pipe. This valve holds the water in the suction pipe. In the farmer's skimming wells, the blind pipe is used directly as suction pipe and the non-return valve is fixed just below the centrifugal pump assembly on the suction side of the system. The present practice of skipping the suction pipe is to reduce the cost of the system. On the other hand, it might be one of the reasons to drop the water level from the blind pipe, as there is nothing to retain water in this pipe and hence needs priming each time before operation.

To provide state-of-the-art solution of the priming problem, different field trials were carried out. The possible causes of the drop in water level in blind pipes were discussed with farmers and evaluated accordingly. Starting with their assumption of leakage in non-return valve, a storage tank was attached with the delivery pipe of the well above the pump (Figure 8). The tank was filled when the well was in operation and the stored water in the tank then was used for priming purposes in next run. There was not much success in this system of priming. The time consumed to lift water by the pump was almost same. This system only facilitated the priming procedure but did not provide a solution. It was also observed that the water remained in the delivery system above the non-return valve, which clearly rejected the hypothesis that the leakage was through non-return valve.

The next step was to look below the non-return valve. It was considered that the water in the blind pipes seeped out of the strainers into the aquifer to maintain water level in the surroundings and air took the place of water in the blind pipes. The source of air was unknown. It might be from some loose joints in the system. The second step to find solution of the priming problem was based on the above explanation. This time, instead of filling the pump above delivery side, the system was modified to fill the blind pipes. For this, storage tank was attached with the delivery pipe and was filled during pumping (Figure 9). An outlet from the tank was provided in the tee joint to refill the blind pipes. Before running the pump, the water from the tank was released into the delivery pipes to fill them. It was observed that the volume of water in the storage tank was not that enough to fill the blind pipes fully. The reason might be the release of water into the aquifer from the strainers as the water tried to maintain the level in the system. This system would have worked if the size of the tank were larger and the water would have been poured instantaneously.

Working on the same problem, a third option was tried which was very close to the conventional design of the wells. The non-return valve below the pumping assembly was replaced with non-return valves between the blind and the strainer at each strainer (Figure 10). This arrangement worked successfully and solved the problem of priming. The total expenditures on these valves were almost the same as that of conventional non-return valve but had benefits in terms of saving in fuel consumption and the time spent to prime tubewells without this arrangement.

Water Quality

In the Indus Basin of Pakistan, the groundwater quality of most of the skimming wells is saline and saline sodic (Kahlown, 2000). Farmers have their own indicator to test the quality of skimming wells. About 88% farmers assess the quality of tubewell water from the crop growth, 9% by tasting it and only 3% by laboratory testing. They term the waters sweet and brackish on relative basis and compare it with the quality of canal water. Farmers complained that using poor quality water, their land have developed salinity. The source of their knowledge is the white patches on the soil they observe after irrigating the fields with deep water. The other indictors used by the farmers to assess the soil degradation are; (i) soil hardness, (ii) low germination rate, (iii) no crop, (iv) late field capacity condition, (v) stunted crop growth, and (vi) low infiltration rate. Most of the farmers with shallow tubewells complained that the water quality remains acceptable during first one or two years of tubewell installation but deteriorate later on. They use the growth and fruit of their citrus gardens as an indicator to water quality. Their indicators could not be judged on scientific bases in the present study.

The water quality of the pumped water mainly depends upon the design and operational parameters of the tubewell with reference to the hydro-geological environment of the region. In the design parameters, the depth of the well is of significant importance. The method adopted for deciding the depth of the well may help in getting better quality of water. Moreover, the operational management strategies may help to avoid extraction of poor quality water. These may include operating tubewell intermittently rather than continuously. For the study area, maximum six hours pumping per day was proposed (Ashraf et al., 2001). The intermittent pumping not only maintains the water quality but also a minimum suction lift that helps get a relatively good discharge.

Sand in Pumped Water

About 39% farmers reported sands in their pumped water. In farmers' perception, the sand in pumped water is due to large openings and cracks in PVC strainers. Farmers are not very much worried about the minor quantity of sand. They told that only excessive amount of sand might cause land subsidence and hence collapse of borehole. When asked about the remedial measures to reduce or possibly stop it, they proposed using fine porous synthetic material to wrap the strainers before installation. When the reasons of cracks in the strainers were discussed, they were of the view that large pumping unit (high suction) and low quality material (especially strainer and blind pipes) were the reasons.

During diagnostic analyses, it was observed that the pumped water had sand in it for a very short period, only one or two minutes at the initial stage of pumping. The sieve analysis of sand collected during pumping showed that the particle size of sand was less than 0.40 mm. The one possible reason might be the use of commercially available strainer for all areas without considering the sand grading of the areas. Table 5 shows the percentage of different sand particles at different locations in the study area. The different proportions of finer sand particle demands customized well screen rather than general one. The use of same slot-size strainers may cause sand problem in media having high percentage of finer sand particles as compared to the media where the percentage of fine sand particles is low. Anyhow, this small amount of finer particles cannot be avoided in the present practices and it did not have any significant effect either on pumping unit or on the quality of water (from irrigation point of view).

The other reasons, which may cause the sand in pumped water are; (i) the coir string strainers becomes weak with the passage of time and also due to bacterial action and this results in string breakage, (ii) the joints in strainers and blind pipes become loose as a result of water hammer, (iii) small cracks in PVC pipes which develop further with the vibration of pumping machinery, and (iv) fine silt particles enlarge the openings of the strainer while passing through PVC strainers.

Reduction in Well Discharge

About 28% of the farmers in the study area reported reduction in well discharge after 2 to 4 hours of operation. The problem occurs both in shallow and skimming tubewells. Sometimes, the suction break occurs due to damaged strainers. To detect damaged strainer in the skimming tubewells, farmers have developed their own methodology. In the first method, pump is kept running and the hissing sound of the air is listened from the pipes. The damaged pipe gives the hissing sound. In the second method, the pipe from each strainer is disjoined from the tee-joint and a hand-pump assembly is attached to each pipe. The hand-pump is operated and if it does not lift water, the strainer is considered as non-functional. The non-functional strainers are repaired, replaced or plugged permanently. This method puts extra economical burden on the farmers as the horizontal pipes have to cut for hand pump installation and then these pipes are rejoined together or some times have to replace. During fieldwork, the authors of this paper proposed a method to diagnose the problematic strainers. For this purpose, the pump is dismantled and outlets in the tee joint are closed with the help of some cloth or wooden peg. One outlet is opened and the tee joint is filled with water. If the water level in the tee joint reduces, this will indicate a leakage in the strainer. Otherwise, the next outlet is opened and tee joint is refilled with water. The same procedure is repeated until the defective strainer is found. The present method of using tee joint is economical and reduces the chances of leakage from new joints.

The reduction in well discharge was quantified by observing a 16-strainers skimming tubewell at farmer's field. The well discharge was measured at the initial stage of pumping and just before closing the well operation. The reduction in discharge increased with the operational hours (Figure 11). The possible explanation is that the drawdown around the well increases for long operational hours and hence the total head for the pump. From the pump characteristics, it is well established that the discharge of the pump reduces if the total head is increased.

During well operation, as the drawdown exceeds below the depth of the blind pipe, the strainer may expose to air and suction break occurs in this borehole. In this case, the skimming well may stop lifting water due to entrapped air in the pump and complete suction break may occur. During diagnostic analysis no single case was observed where the suction break occurred. High transmissivity of the aquifer under Indus Basin does not support farmer's claim of suction break as well. If this happens at some place, this might be regarded as design problem of the skimming well such as shorter length blind pipe then expected drawdown. Moreover, the operational strategy of the intermittent pumping may help to maintain a minimum suction head and hence helps get a good discharge.

CONCLUSIONS

1. The PRA techniques helped in sharing information regarding the performance, practices and constraints with farmers' skimming wells. Group discussions with farmers gave them confidence and many information were shared during these group discussions, which farmers were reluctant to share during individual talks. Moreover, arranged group meetings proved more effective than surprise visits to farmers.

2. The study showed that farmers were more interested in quantity of the water rather than the quality and their well design was influence by this factor. As a consequence, the skimming wells were not performing their operation economically.

3. The decision regarding the well design lies with the farmer and he picks one of the design options provided by the local driller. While giving the options, the local driller has his own business interest.

4. Both the farmers and drillers are the target group to enhance their technical knowledge. Any training program to enhance the technical knowledge must involve both the farmers and drillers.

5. A wide variation in farmers' skimming well design indicated the absence design codes for farmers' skimming wells. There is an

imperative need to define the design and operational parameters of the skimming wells on the bases of hydro-geological environment of the area.

6. The participatory services helped in solving the problems with farmers' skimming wells. The systematic and step-by-step approach helped in developing methodology to under take technical research in farmer's friendly way. Moreover, the technical intervention with farmers' participation improved the skimming well technology. The results of these methods showed that farmers own the outcome of such research.

7. On-field training or seminar may help to disseminate the research findings at large scale among farmer's community.

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Table 1. Techniques used for participatory rural appraisal.

S. No.	PRA Techniques	Purpose
1	Semi-structured Interview	To obtain insights into farmers' perception, their constraints and possible improvements in skimming wells.
2	Trend Line	To identify the months with high water table, peak water demand for crops and high skimming well operational hours.
3	Pie Chart	To observe the change in cropping pattern after installation of skimming well and percentage contribution of well water.
4	Field Walk	To have more insight into the problem mentioned by farmers and help to identify and locate additional problems with the skimming wells.
5	Flow Chart	To visualize cause-effect relationship and identify solution to solve the problems with farmers skimming wells.
6	Mapping	To understand the design of skimming wells, spatial distances between strainers and length of strainers and blind pipe.
7	Preference Ranking	To identify and prioritize skimming well problems.

Table 2. Water quality profile of test borehole at a well site.

S. No.	Sampling Depth (m)	EC ($dS\text{-}m^{-1}$)	pH
1	6.0	0.904	7.67
2	9.0	0.862	7.62
3	12.0	1.002	7.68
4	15.0	0.742	7.64
5	18.0	0.906	7.83
6	21.0	1.682	8.01
7	24.0	1.542	7.91

Table 3. Variation in strainer size with depth of shallow tubewells.

Depth of Shallow Tubewell (m)	Diameter of Strainer (cm)	Length of Strainer (m)	Area of Strainer (m^2)
30.0	10.0	24.0	7.54
	12.5	24.0	9.42
	15.0	24.0	11.31
	15.0	21.0	9.90
	17.5	24.0	13.19
	17.5	21.0	11.55
	20.0	24.0	15.08
	20.0	21.0	13.19
34.0	15.0	29.0	13.67
	15.0	27.0	12.72
	15.0	24.0	11.31
	17.5	27.0	14.84
	20.0	27.0	16.96
37.0	15.0	30.0	14.14
	15.0	29.0	13.67
	15.0	27.0	12.72
	20.0	30.0	18.85
	20.0	24.0	15.08
	20.0	21.0	13.19

Table 4. Variation in length of the strainers.

Number of Strainers	Diameter of Strainer (cm)	Length of Strainer (m)		
		Maximum	Minimum	Average
4	7.5	12.0	8.0	10.0
6	7.5	9.0	7.0	8.0
10	5.0	12.0	8.0	9.6

Table 5. Sand particle distribution at different locations in the study area.

Particle Size (mm)	Percentage of Different Sand Particles						
	MREP Farm	MN-93	MN-80	Nasir Farm	Akram Farm	Tariq Farm	Nawaz Farm
> 0.85	0	0	0	1	2	2	1
0.85 – 0.40	4	7	8	3	4	2	5
0.40 – 0.30	29	26	34	20	19	7	18
0.30 – 0.25	24	18	19	23	17	9	13
0.25 – 0.18	27	27	19	33	30	23	22
0.18 – 0.15	6	7	5	7	19	7	6
0.15 – 0.08	6	8	10	6	3	34	27
< 0.08	4	6	5	7	7	16	7

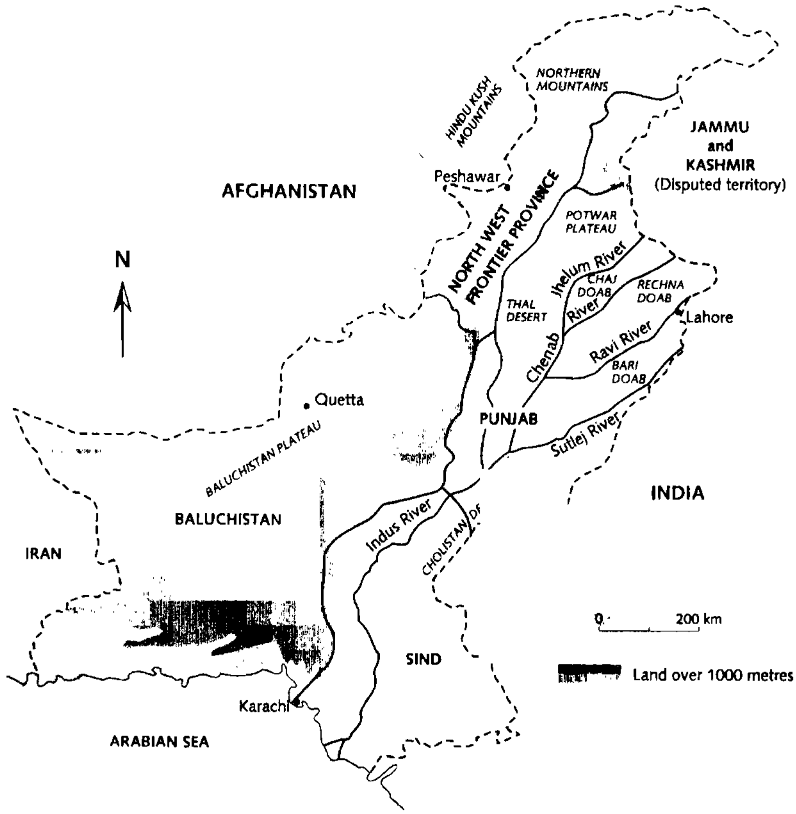

Figure 1. Location of study area in the Indus Basin of Pakistan.

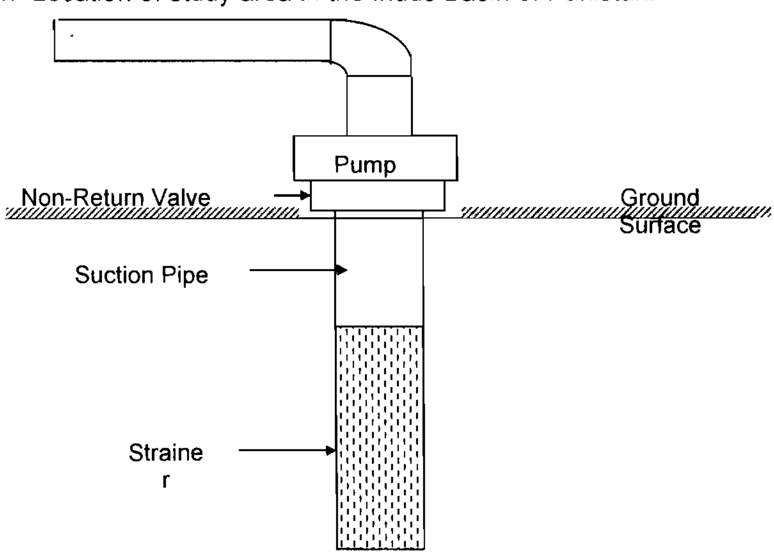

Figure 2. Schematic presentation of farmer's shallow tubewell.

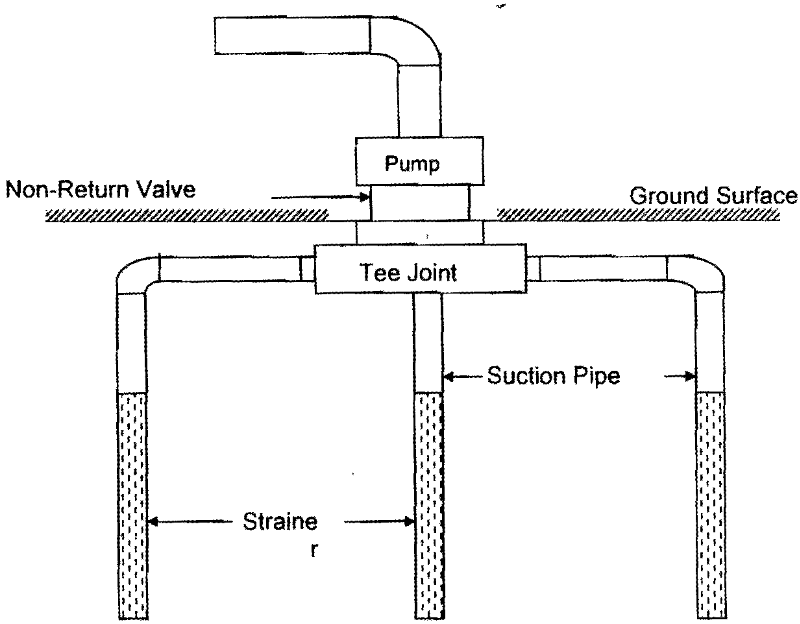

Figure 3. Schematic presentation of farmer's skimming tubewell.

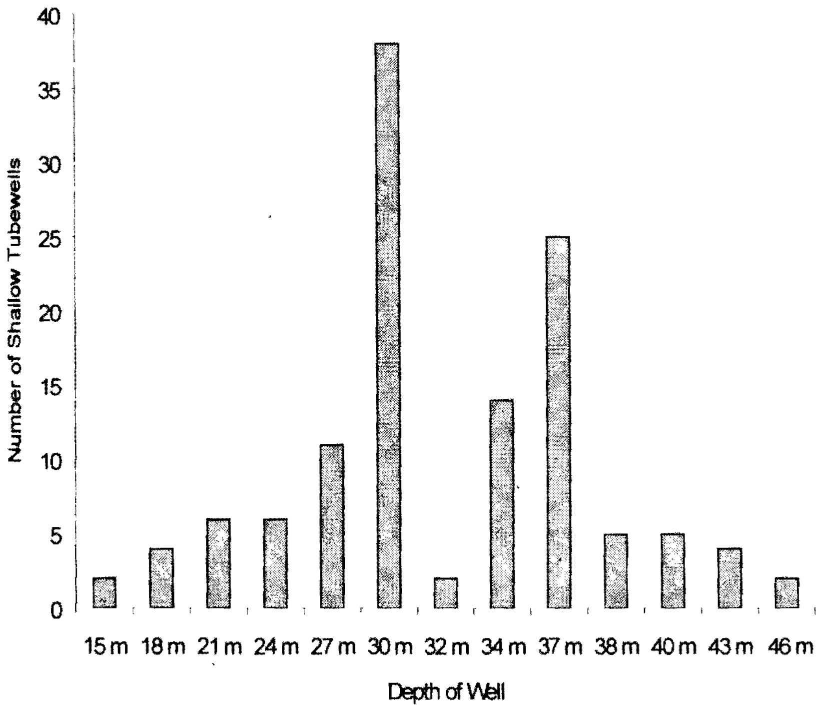

Figure 4. Distribution of depth in shallow tubewells in the study area.

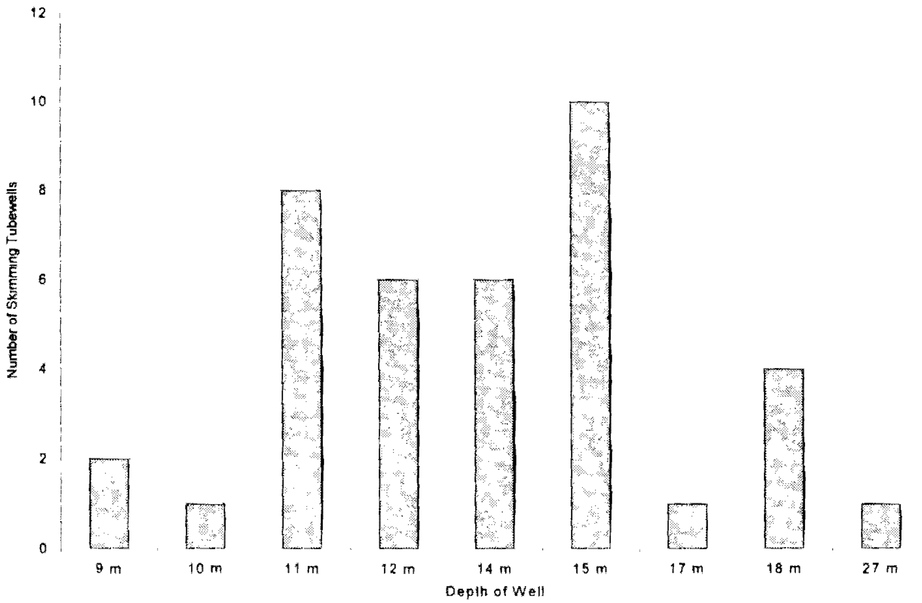

Figure 5. Distribu tion of depth in skimming tubewells in the study area.

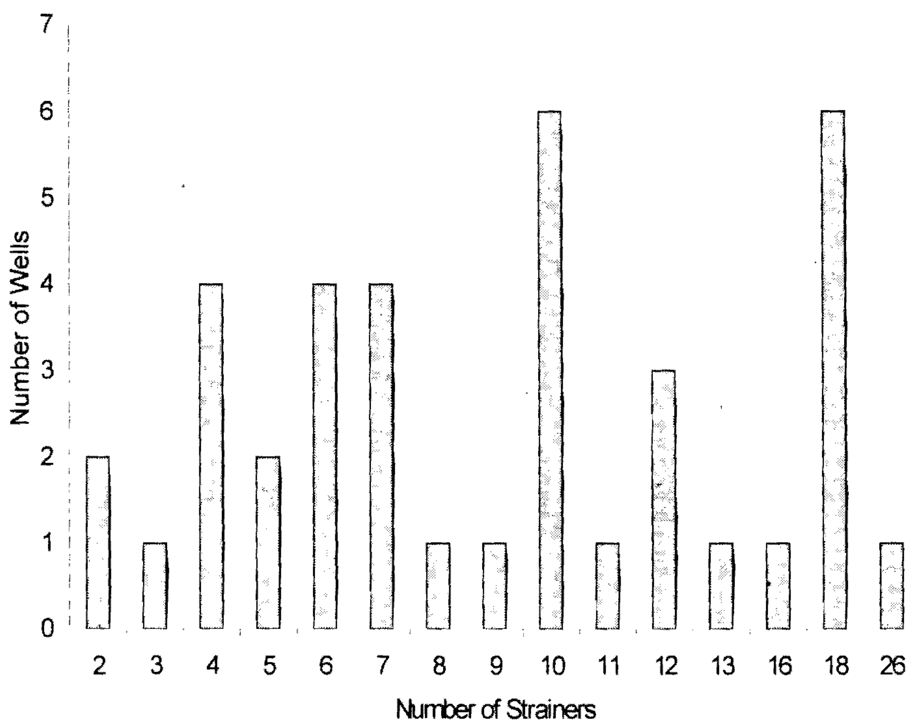

Figure 6. Distribu tion of skimming tubewells in the study area.

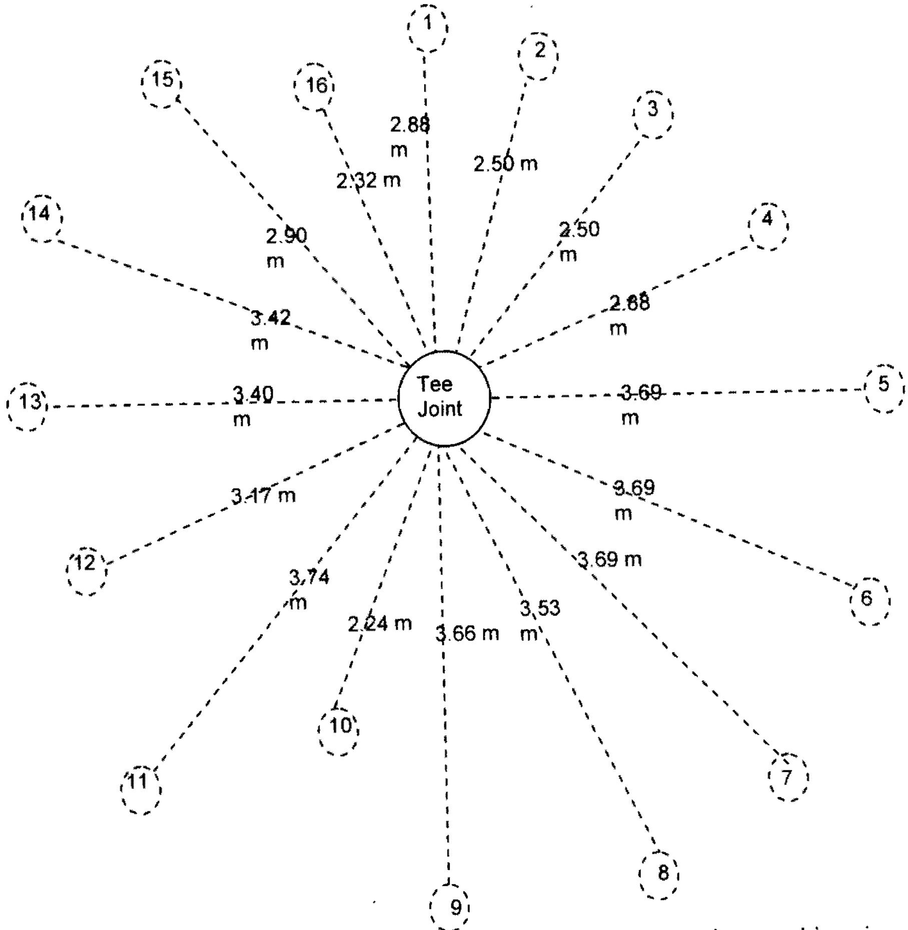

Figure 7. Arrangement of horizontal distances in 16-strainers skimming tubewell in the study area.

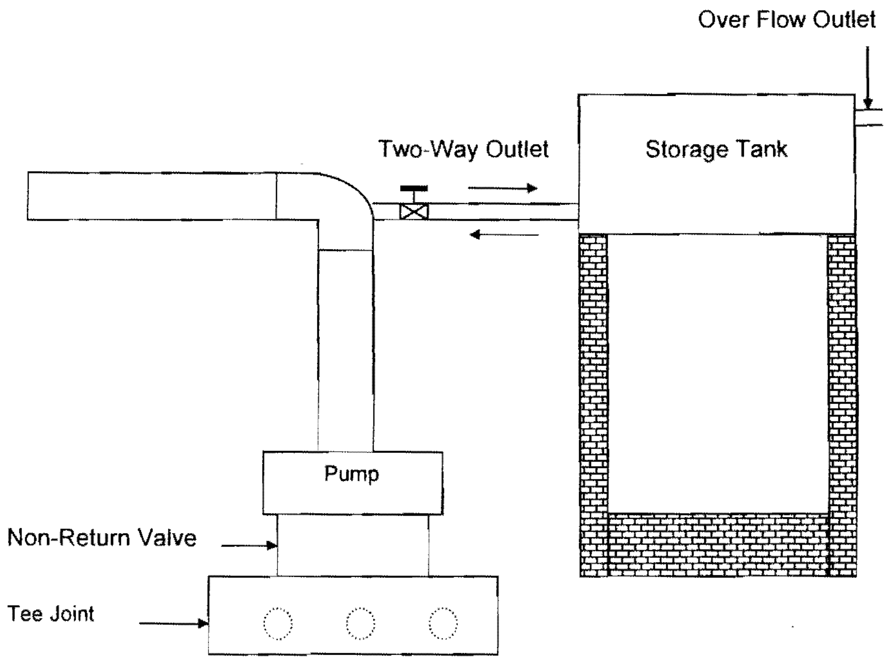

Figure 8. Filling arrangement above the non-return valve.

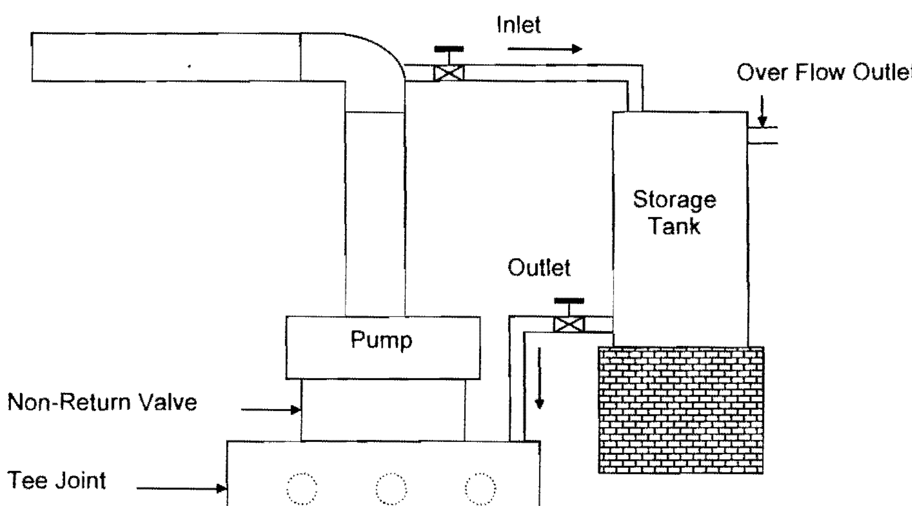

Figure 9. Filling arrangement below the non-return valve.