Methodology for Identification of Potential Sites for Artificial Groundwater Recharge in Punjab Province of Pakistan

Canadian Journal of Agriculture and Crops
Vol. 7, No. 2, 46-77, 2022
e-ISSN: 2518-6655

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ABSTRACT

Groundwater is a precious gift of nature and is being used for drinking, agricultural, industrial, livestock. In Punjab province of Pakistan groundwater is contributing about fifty percent towards irrigation water requirements where a large aquifer underlying the Indus River Basin (IRB) is being depleted rapidly. In the present research a methodology/criterion has been developed and applied for identification of the suitable sites for recharging the aquifer artificially in the Punjab province in Pakistan. Major activities carried out include the installation of exploratory boreholes, collection and analysis of soil and water samples, determination of aquifer parameter (hydraulic conductivity) in laboratory. Other field observations include observation of groundwater levels, land availability, water availability, and physiographic features. On the basis of field surveys and laboratory investigations, criteria for identification of potential sites for artificial recharge to augment the groundwater reservoir has been developed. Keeping in view the parameters adopted in the criteria, thirteen potential sites in the critical areas have been identified for artificial recharge to replenish the depleting groundwater levels. This research provides guidelines for the decision-makers for future investment for sustainable groundwater management.

Keywords: *Groundwater, Artificial recharge, Aquifer, Lithology, Rainfall, Indus-River-Basin, Punjab, Pakistan.*

DOI: 10.55284/cjac.v7i2.657
Citation | Ghulam Zakir-Hassan; Jehangir F Punthakey; Faiz Raza Hassan; Ghulam Shabir (2022). Methodology for Identification of Potential Sites for Artificial Groundwater Recharge in Punjab Province of Pakistan. Canadian Journal of Agriculture and Crops, 7(2): 46-77.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
History: Received: 2 May 2022/ Revised: 10 June 2022/ Accepted: 24 June 2022/ Published: 7 July 2022
Publisher: Online Science Publishing

Highlights of this paper

- Development of a criteria for selection of sites for artificial recharge.
- Methodology for selection of potential sites for managed aquifer recharge for sustainable groundwater management.
- Investment options for decision making water resources planners in Pakistan.

1. INTRODUCTION

Water is an essential commodity for existence of life on planet. An assured supply of wholesome water has, therefore, been the prime concern of all societies [1]. In our own time the increasing stress on the supportive and assimilative capacities of water systems has led to a growing realization that it is only through a scientific approach to their management that we can hope to sustain the quality and regular availability of this basic human requirement. The need for appropriate integrated studies in developing countries is all the more important in view of an increasing population, widespread aridity and scarcity of fiscal resources, and changing hydro-meteorological conditions. Groundwater, surface water and land comprise a complex interlocked system and they must be considered and managed in their totality towards making the most optimal use of this precious resource. With the advent of remote sensing and sophisticated data processing techniques, the speed and scale of investigations of visible resources such as land and surface water have greatly improved. An understanding of the invisible groundwater regimes and quantification of their characteristic parameters, however, continue to remain mostly inferential and indirect. Groundwater resources are now being increasingly tapped to meet societal needs on account of their possible availability in the vicinity of the consumer. However, it is important to recognize that although groundwater has ubiquitous occurrence and vast magnitude, its potential as a perennial source is subject to wide spatio-temporal variations. It is renewable but not inexhaustible. It is underground but not entirely protected from pollution [2].

As indicated by many researchers and scientists, serious water scarcity situation may occur in Pakistan and the country may suffer badly, if necessary, measures are not taken from today for the management of water resources [3]. Since last many years, rapid increase in population has resulted in over extraction of ground water especially in the urban areas to meet with human demands due to which underground watertable is depleting at alarming rates [4]. Also in rural areas, surface water is insufficient to meet with the demands of agriculture sector due to continuous increase in food and fiber requirements. It is worth mentioning that groundwater is contributing about 40% of total water being used for irrigation purposes in the Province, while almost 100% demands for drinking water are being met from groundwater [5]. The un-planned pumpage of groundwater is also causing salt-water intrusion into fresh groundwater due to which sweet groundwater resource is becoming scarce [6]. This needs formulation of long term policy framework and comprehensive planning to guard against fast depleting ground water resources [7].

This critical situation needs to be addressed for our future generation and country's economic growth. During monsoon rains, when lands are generally saturated and need no canal irrigation, the surplus canal water can be injected into aquifer after necessary de-silting and treatment. The rainfall water in suitable depressions and natural drains can also be used for recharging purpose. Realizing the intensity of problem, the IRI conducted research studies on artificial recharge of groundwater aquifer funded by the Provincial Government under annual development program [8].

It is a great misfortune that a significant volume of precious surface water annually flows down to sea due to insufficient number of large dams for storage of surplus [9, 10]. On the other hand, more than one million tube wells are extracting groundwater on continuous basis. The rate of natural re-charging (approx. 30 MAF annually) is lower than the rate of extraction (50 to 55 MAF annually) [11]. This situation has resulted in tremendous depletion of groundwater levels; for example, in Lahore, where more than 425 tubewells are extracting about 755 Million gallon of groundwater per day for drinking purpose, while natural re-charging of groundwater aquifer is almost negligible due to construction activities and pavements of streets and roads [4]. The only source to recharge Lahore aquifer is Ravi River which remains nearly dry except during monsoon season; the net result being that watertable in Lahore city area has depleted down to around 100 ft or even more in some cases [12].

The process of groundwater recharge is like refilling a leaky tank. Over the long term, recharge is generally balanced by discharge to soil surface or deeper parts of the groundwater system or by up take by plants. Natural recharge is termed as the natural process in hydrologic cycle by mean of which water from the soil surface infiltrates down and some part of it ultimately reaches the groundwater reservoir. However, this process of natural recharge is altered/affected locally by increase in impervious surfaces due to urbanization and pavement of roads/streets and other activities natural or man-made which cause changes in land use. Climate changes (e.g., less rainfall) also result in decreased in recharge of groundwater.

Groundwater is a far more important resource than is often realized. Excluding the water locked in glaciers and icecaps, about 97 percent of the World's fresh water is groundwater while streams, rivers and lakes hold only about 3 percent [13].

The growing future competition for water in the Pakistan and elsewhere around the world is leading to even greater use of this enormous water resource. As part of this trend, there has been increased interest in the use of artificial recharge to augment groundwater supplies all over the world. Artificial recharge is a process by which excess surface water is injected into the ground either by direct or indirect recharging techniques by interfering with natural surface and sub-surface conditions to replenish the groundwater reservoir for its future uses.

The most common purpose of artificial recharge is to store water under ground during monsoon period to meet water demand during shortage period. Recovered recharge water is especially well-suited to non-potable uses; under appropriate conditions and where better sources are not available, recovered recharge water can also be an option for potable use. Artificial recharge can be used to control sea water intrusion in coastal aquifers, control land subsidence caused by declining groundwater levels, maintain base flow in some streams, raise groundwater levels to reduce the cost of ground water pumping, conserve or dispose the flood waters, reduce the surface drainage needs during heavy rainfalls and to maintain the groundwater quality by controlling the saline water intrusion etc.

In order to ensure that water quality remains with in permissible limits, it is important for the countries to have sufficient policies regarding recharging the aquifer. To prevent groundwater pollution, discharge from the aquifer should be regulated. While considering the disposal and storage of water into groundwater reservoir the vulnerability of the aquifer should specially be taken into account.

Dr. Nazir Ahmad, an eminent scientist has stressed on "Artificial Recharge" of Aquifer in his papers, publications and letters to IRI, WASA, PCRWR, etc. He was always much worried about Lahore aquifer. He estimated the amount of rainfall water available during Monsoon. He suggested using this water to recharge the Lahore aquifer. He pointed out that huge pumping of groundwater has lowered the watertable from a depth of 15 ft. in 1960 to a depth of 70 ft. in 1987, with the increase of Lahore population the watertable will further lower to the depth of about 90 ft. within 20 years. He also indicated the presence of inferior ground water at 19 Km away in the South of Lahore near Raiwind. It is worthwhile to check the inflow of this inferior water towards a depression of more than 70 ft. He suggested i) to install electrical gadgets at suitable sites and depth to determine the amount of saline water and ii) to estimate by numerical modeling, the optimum sites of recharge, future decline in groundwater and possible intrusion of saline water into the dewatered area of Lahore.

Ahmed [14] pointed out that the area of Narowal, Pasrur, Chewinda receive about 32 inches summer rainfall which accumulates between Marala, Ravi, BRBD Link and in Deg Catchments. According to his point of view this water can be used to improve the groundwater levels in Lahore areas. He also suggested, particularly for Lahore aquifer, recharge for growing population of Lahore that:- i) this water can be brought through BRBD to Lahore Branch Canal and a part discharged to River Ravi for recharging the Northern part of Lahore, ii) for recharging the eastern and middle part of Lahore, it is suggested to install recharge wells along right bank of BRBD between Ravi Syphon and Badian and along both the banks of Lahore Branch Canal and iii) different types of recharging techniques can be tested in these areas due to availability of excess rainwater. He concluded that Lahore area receives about 12 to 14 inches of summer rainfall which accumulates in the depressions, which have to be pumped for its disposal. Therefore, to conserve this water; recharge wells should be installed at some selected places in Lahore.

IRI [15] conducted a study on artificial recharge under semi field conditions at Field Research Station Niazbeg. It was concluded that, choking of strainer is the major problem during recharging of ground water artificially by gravity well. It was suggested that water should be treated to make it free of silt and physical debris etc. before injection to groundwater storage.

Rama [16] worked on the possibilities of underground storage of surplus flood water in India. He described that generous rainfall during the months of July-August-September causes floods in Gangetic basin, followed by shortage of supply during dry months. The physiography and topography of the region provides a very limited scope for surface storage. There exists the possibility of storing some of the surplus run-off of the rainy season in underground reservoirs, for use during the dry period. The scheme envisages emptying the existing natural reservoirs which are normally always full, and which are likely to fill by themselves after they are emptied, without any extra engineering. The artificial part of the scheme consists in generating productive consumption, by intensive irrigation, for the large quantity of water withdrawn. The emptied reservoir is expected to absorb a part of the flood pulse also. The scheme is likely to have maximum potential in the Gangetic plain. The most promising reservoirs, meeting the above criteria, appear to be the sandy aquifers connected with the beds of seasonal streams.

Firozudding, et al. [17] worked on induced recharge to deep aquifer for augmenting the water supply scheme. They found that there is mounting concern regarding the problem of developing adequate water supplies to Ambala urban area as the locally available ground water supplies through tubewells will not be able to meet the growing demands. They examined the results of the studies carried out to delineate the watertable aquifer along the riverine tract of Dangri River, the geometry and the productivity of the aquifer, its capacity to hold the required amount of water and possibilities of induced recharge for the river. It is estimated that a quantity of 2.66 MCM can be pumped out from the aquifer during the dry season. The estimated induced recharge from the river to the aquifer is about 0.833 MCM during the monsoon season. A possibility of development to the extent of 7.30 MCM of the deeper aquifers occurring below 150 m depth has also been discussed as an additional source to augment the water supply. The results of their investigation showed that the highly permeable granular zones, which can act as the most favorable zone for induced recharge, occur in the area around Khelan, Babial and Kajkipur along the riverine tract of Dangri River with average saturated thickness of about 14 meters. It is suggested to construct a well field in this area, with an average discharge of 726 m /day from each well. The well field should be laid parallel to the river on its western bank at a distance of 100 m from the river keeping spacing of 300 m between two shallow tubewells of 30 m depth. The corresponding drawdown in the center of the well field is calculated to be 7.77 m. About 10986 m/day of ground water can be withdrawn during summer months which can be utilized for augmenting the water supply to Kamala urban area. It is expected that with intensive development, water levels will go down in these areas as the system tends to be in dynamic equilibrium thereby creating additional storage space for induced infiltration. It has been estimated that a quantity of 0.833 MCM can be recharged by induced infiltration during monsoon season from the Dangri River. Further augmentation of water supply to Ambala town to the tune of 7.30 MCM of water per annum can be attempted by tapping the deeper aquifers in the depth range of 150 to 450 m bgl through a well field of 10 tubewells with a pumping rate of about 2000 m /day at each well. The average catchment area is 8.5 km^2 with average gross storage of 200 TCM-both with a high coefficient of variation. There are about 475 such tanks in the Sina and the Man basins where a representative study is made by selective monitoring of tank levels, contents, ground water levels in wells, and evaporation rate. Evaporation on an average account for 10. 7% of total depletion of tank contents. An average percolation rate of 45 mm/day was estimated for post monsoon period which may include the visible seepage appearing in water courses downstream. Those wells which are influenced by percolation show increased yield of 10 to 30%, by taking into consideration water levels and time factor. Some of the aspects of percolation tanks are outlined in the light of the findings. Storage changes in tanks are affected by many factors – from surface runoff of catchments areas, by direct addition from rainfall, and from groundwater appearing as effluent seepage. The decrease in storage can be accounted for as recharge to groundwater bodies evaporation, and other usage through distribution works. So far as the percolation tanks are concerned the loss in storage is entirely due to percolation and evaporation. A certain amount of groundwater may reappear as visible seepage or groundwater runoff, or different lengths of time, downstream of the tanks. The processes of evaporation and percolation are more vigorous after the withdrawal of monsoon for obvious reasons. Water stage in the tanks is recorded periodically either on the embankment slope or on the staff gauges specifically erected in the tank. Storage volumes are calculated from capacity curves of the tanks survey. Evaporation from reservoir surface is the other factor to be determined. Pan evaporation data from the nearest meteorological station were taken as representative. Tank evaporation is taken as 0.7 times of Pan evaporation rate observed.

Artificial recharge can take place through direct and indirect methods and most of the country use artificial recharge to obtain different objectives like (i) the maximization of storage (including seasonal, long-term, and drought or emergency water supplies), (ii) physical management of the aquifer, (iii) water quality management, (iv) management of water distribution systems, (v) ecological benefits. The use of recharged water may determine what method, or a combination of methods should be adopted for artificial recharge at a particular site.

Artificial groundwater recharge projects aim at augmenting the natural infiltration of precipitation or surface water into underground formations by some method of construction, spreading of water or by artificially changing natural conditions. Schemes contemplating artificial recharge as the sole objective can be planned or in the alternative artificial recharge can be realized as an objective incidental to certain other developmental programs. For instance, soil conservation practices which aim at conservation of fertile topsoil and improved agricultural practices intended to maintain proper soil structure incidentally help in reduction of surface runoff and maintain high infiltration rates and thus augment groundwater recharge.

Continuous depletion and unplanned pumping of the aquifer at many locations is posting a serious threat for economy of the country and water crisis in Pakistan. This situation has given rise to the different issues like i) uncontrolled and unregulated groundwater abstraction, ii) over depletion of groundwater reservoir, iii) deterioration of groundwater quality iv) increase in cost of installation and operation of tube wells due to decline in watertable, v) saline water intrusion and vi) secondary salinization etc. All these demands some urgent and sustainable planning and management measures to replenish the aquifer for its long-term use without environmental hazards. For this purpose, it is the need of the hour to store and avoid wastage of even a single drop of water. In urban areas natural recharge has been reduced due to urbanization and rainfall water goes waste to surface drains or enters the sewerage system and causes the problem of flooding and/or choking the disposal network during rainy seasons. This water can be diverted and injected to underground reservoir and can prove very helpful in recharging the aquifer.

Natural groundwater resources are understood to be the total amount of recharge (replenishment) of groundwater under natural conditions as a result of infiltration of precipitation, seepage from rivers and lakes, leakage from overlying and underlying aquifers, and inflow from adjacent areas. This definition has been generally accepted.

According to research studies, storing of flood water as groundwater has a number of essential advantages when compared with surface water: as a rule, it is of higher quality, better protected from possible surface pollution including infection, not subject to evaporation, less subject to seasonal and perennial fluctuations, and much more uniformly spread over large regions than surface water. Very often groundwater is available in places where there is no surface water. Putting groundwater well fields into operation can be gradual in response to growing water demand while hydrotechnical facilities for surface water use often require considerable one-time investments. The subsurface reservoir is usually of large capacity. In place of costly dams required to hold water at the surface, smaller and safer structures may suffice to hold back flood flow until it can be put underground. Water may be stored underground for use during a series of years of subnormal rainfall.

The size of available underground storage depends upon the volume of porous material between the "seasonal high" position of the watertable for the year in which storage operations are conducted and the watertable which develops due to effluent seepage. If pumping plants are so arranged that they draw down the watertable throughout the area of effluent seepage, occurred due to a high-watertable may be overcome and a large available storage space maintained throughout the year and throughout a wet cycle than under natural conditions. A coordinated plan of water storage, therefore, involves installation and operation of pumping plants.

From the legal standpoint, landowners have cause for action if their properties are damaged by a high-watertable due to artificial storage of groundwater. It has been suggested that the watertable at the end of a wet cycle of years ("cyclic high") is the upper boundary of the groundwater reservoir and filling the reservoir to this level is permissible. Whether or not the "cyclic high" position of the watertable will be adopted by the courts remains to the seen. One can foresee numerous lawsuits from spreading operations now contemplated in southern California, and it would be advisable to study the probable effluent seepage at various watertable stages before spreading operations are initiated.

IRI [15] conducted a study on artificial recharge under semi field conditions and concluded that, choking of strainer is the major problem during recharging of ground water artificially by gravity well. It was suggested that water should be treated to make silt free before injection to groundwater.

Managed aquifer recharge (MAR) has become a widely being used tool for augmentation of depleting aquifer across the globe and it has many benefits as well [18, 19]. MAR models have worked successfully in many places in South Asia as well [20]. In Punjab Pakistan, surplus rainfall and floodwater is available during the monsoon periods (June to October). This water if harvested properly and managed scientifically, can be stored in the underground storage. Research studies have indicated that rainwater is suitable for MAR is harvested properly [21]. Sufficient storage potential is available in the aquifer underlying the Indus River Basin (IRB) in Pakistan [22]. This study has been conducted to carry out field survey and investigations at critical (depleted) sites in the Punjab province of Pakistan. Considering the different requirements for Mar schemes a criterion has been developed to identify the potential and feasible sites for MAR schemes [12].

2. MATERIALS AND METHODS

2.1. Study Area

Present study has been carried out in the Punjab province of Pakistan as shown in Figure 1. Initially fresh data of groundwater levels and quality provided in DLR [23] was taken as reference. Suitable points with respect to water quality and groundwater levels were chosen for physical survey. On the basis of field surveys and investigations, potential sites for recharging the aquifer artificially had been identified. Research activities have been carried out in the province of Punjab especially in critical areas (groundwater highly depleted areas). Groundwater recharge broadly describes the replenishment of water to a groundwater flow system. Recharge, an integral part of the hydrologic cycle, is the process by which water moves to the groundwater and then away from that area though saturated materials [24].

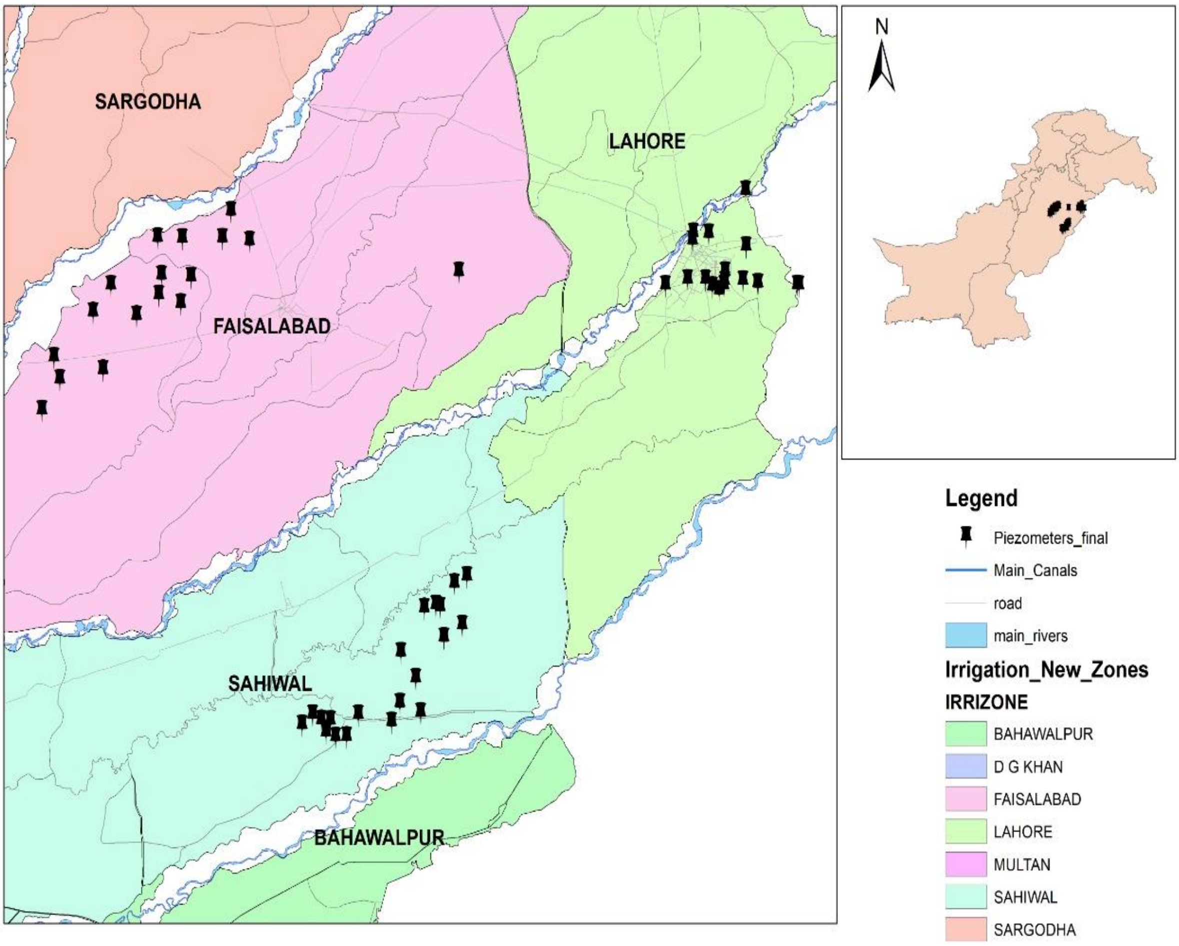

Figure 1. Map of study area showing location of exploratory boreholes at investigation sites in different irrigation zones in Punjab Pakistan.

2.2. Methods of Artificial Recharge

Artificial recharge is the planned human activity for augmenting the amount of groundwater available through works designed to increase the natural replenishment of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction. A variety of methods have been developed and applied to artificially recharge groundwater reservoirs in various parts of the world. Selection of the feasible methods is important and can be challenging. The methods may be generally classified as i) the direct surface recharging techniques, ii) indirect recharge techniques and iii) combination of surface and subsurface methods including subsurface drainage (collector wells), basins with pits, shafts, and wells etc. Oakford [25]. Different methods of artificial recharge have been reviewed and their feasibility at various sites has been explored. Methods of artificial recharge have been ilustrated in the Figure 2.

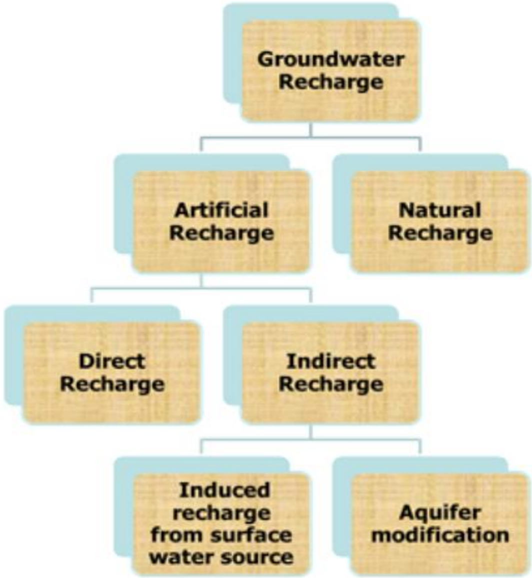

Figure 2. Methods of artificial recharge.

2.3. Direct Methods

Artificial recharge can be accomplished through various direct methods like spreading methods, through injection wells or through pits and shafts. Spreading methods include flooding method, natural channel method etc. The local field conditions including the physiography and hydrogeology of the area have to be carefully considered before selecting a method for artificial recharge.

Direct methods can be divided into surface recharge and subsurface recharge techniques. In surface recharge, water moves from the land surface to the aquifer by means of infiltration through the soil. The surface is usually excavated, and water is added to spreading basins, ditches, pits and shafts and allowed to infiltrate. Generally, surface recharge methods are dependent on the contact time the water has with the soil. Direct surface methods, in comparison to other methods, involve low construction costs and are easy to operate and maintain. Sub-surface recharge methods include recharging the water directly to groundwater by means of recharging wells or shafts. Direct Recharge Methods are shown in Figure 3.

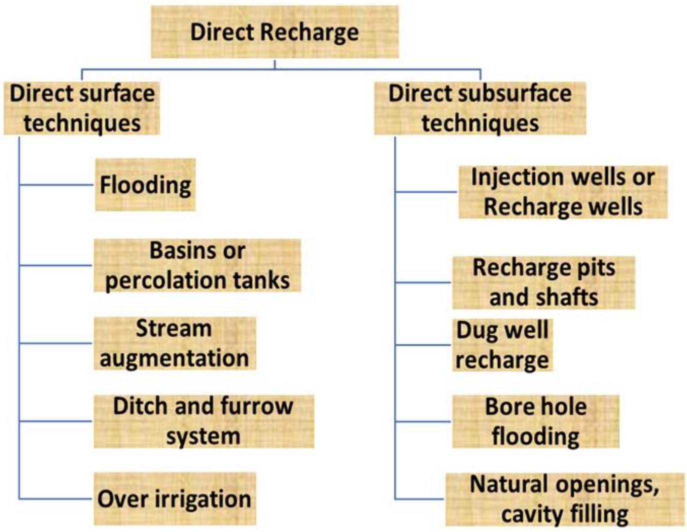

Figure 3. Direct recharge methods.

2.4. Indirect Methods

Indirect methods include installing groundwater pumping facilities near connected surface water bodies to lower groundwater levels and induce infiltration elsewhere in the drainage basin. Indirect methods include modifying aquifers to enhance groundwater reserves as well. Enhanced streambed infiltration is creating a system of wells near a surface water body. One line of wells is set parallel the bank of a river and a second line of wells are located a short distance from the river. Conjunctive wells are screened in both a shallow confined aquifer and a deeper artesian aquifer. Water is pumped from the deeper aquifer and if its potentiometric surface is lowered below the shallow watertable, water from the shallow aquifer drains directly.

2.5. Aquifer Storage and Recovery (ASR)

The idea behind ASR is to take water during times of surplus flows / floods, store it in a large available subsurface reservoir (aquifers), and recover water during dry times when traditional surface water supplies are not available. The watertable defines the top of the saturated part of an aquifer. The area of the aquifer above the watertable is referred as the unsaturated or vadose zone. The conventional supply source is surface water, although there are several examples where water is taken from shallow aquifers and pumped into deeper aquifers. The ideal geological formation for ASR use is a permeable / sandy aquifer that is bounded and has limited hydraulic connection to surface water. Under these conditions, water can be recharged and recovered without significant losses during the storage period. The surface water used for recharge should have low suspended solids to prevent clogging of the wells by sediment or bacterial growth.

Beyond the facilitation in permitting new water supply, ASR can provide economic benefits to the water system managers. Drinking water systems are designed to meet peak needs. The result is that costly infrastructure, such as surface water treatment plants; operate at below capacity during the off-peak season.

Expensive expansions of existing surface water treatment plants to meet projected summer demand peaks can be substituted by incorporating an ASR program. Under-utilized existing facilities can be used to provide treated water for recharge while increased peak demand can be met by recovering the recharged water from new ASR wells.

2.6. Sub-Soil Parameters

Analysis of soil samples has been carried out to obtain the soil classifications and grain size distribution below the soil surface up to the deep aquifer. The type of strata where water is to be recharged plays an important role as sandy formation will support the recharge process and vice versa. This test is performed to determine the percentage of different grain sizes contained with a soil. The mechanical or sieve analysis is performed to determine the distribution of the courser, larger sized particles and the pipette method is used to determine the distribution of the finer particles. Soil classification according to texture is usually done by means of triangular diagram [26] .

2.7. Sampling for Groundwater Quality

Total 60 No groundwater samples (one from each borehole location) or from nearby source were collected. Water samples were analyzed for calculating the concentration of various Cations and Anions.The sample analysis would focus on the three major conventional water quality parameters i.e., Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC). Data and presented in Annexure A (supplementary material)

2.8. Depth to Watertable

Although basic purpose of installing the exploratory bore holes was to determine the soil classification in critical areas, observations of groundwater levels was also carried out. Groundwater levels of 60 No. exploratory boreholes have been recorded twice, one at the time of boring and 2nd during pre-monsoon (June 2009). Observations of groundwater levels from these already installed exploratory boreholes in the field during the year 2008-09 have been observed to determine the fluctuations in watertable in different irrigation zones. Some glimpses from field data observations are shown in Figures 4, 5 and 6. Data on locations addresses, depth to watertable and other features of exploratory bore holes are given in Annexures B and C (supplementary material).

Figure 4. Monitoring of groundwater levels in field.

Figure 5. Monitoring of groundwater levels in field.

Figure 6. Drilling of exploratory boreholes in field.

3. RESULTS AND DISCUSSIONS

3.1. Analysis of Soil Samples

Soil samples from the exploratory boreholes from depths where strata physically changed were collected at site. These were analyzed in the Soil Mechanics Laboratory of Irrigation Research Institute (IRI) to determine the soil stratification/gradation. For this purpose, Soil Triangle of ASTM has been used. The soil samples from each borehole for finding out permeability were also collected and analyzed in the laboratory. Bore logs of all 60 sites up to depth of 100 ft have been prepared being used as the baseline information for identification of potential sites. Soil samples collected from all borehole's sites were analyzed to determine the sub-surface local lithology at a specific location and aquifer parameters to proceed further for artificially recharging the aquifer. Overall objective of the soil analysis is to determine the soil and aquifer parameters which are very vital for recharging the aquifer by some artificial method.

The Zone wise break up of soil samples collected and analyzed in the IRI Soil Mechanics Lab is given in Table 1. A typical bore log is shown in Figure 7.

Table 1. Irrigation Zone wise break up of soil samples collected.

Sr. No	Name of irrigation zone	No of exploratory boreholes installed	No of soil samples collected
1	Lahore Zone	31	363
2	Multan Zone	9	96
3	Faisalabad Zone	20	225
	Total	60	684

3.2. Groundwater Quality

The exploratory boreholes were dug in Lahore, Multan and Faisalabad Irrigation Zones of the Punjab for preliminary investigations. The groundwater samples from nearby source were collected from 58 sites for checking groundwater quality. The results of chemical analysis of these samples are given in Annexure A (supplementary material). The results indicate that out of 58 sites, groundwater water quality at 14 preliminary investigation sites is unfit for irrigation purposes and thus recharging aquifer at these sites is not economical and hence not recommended.

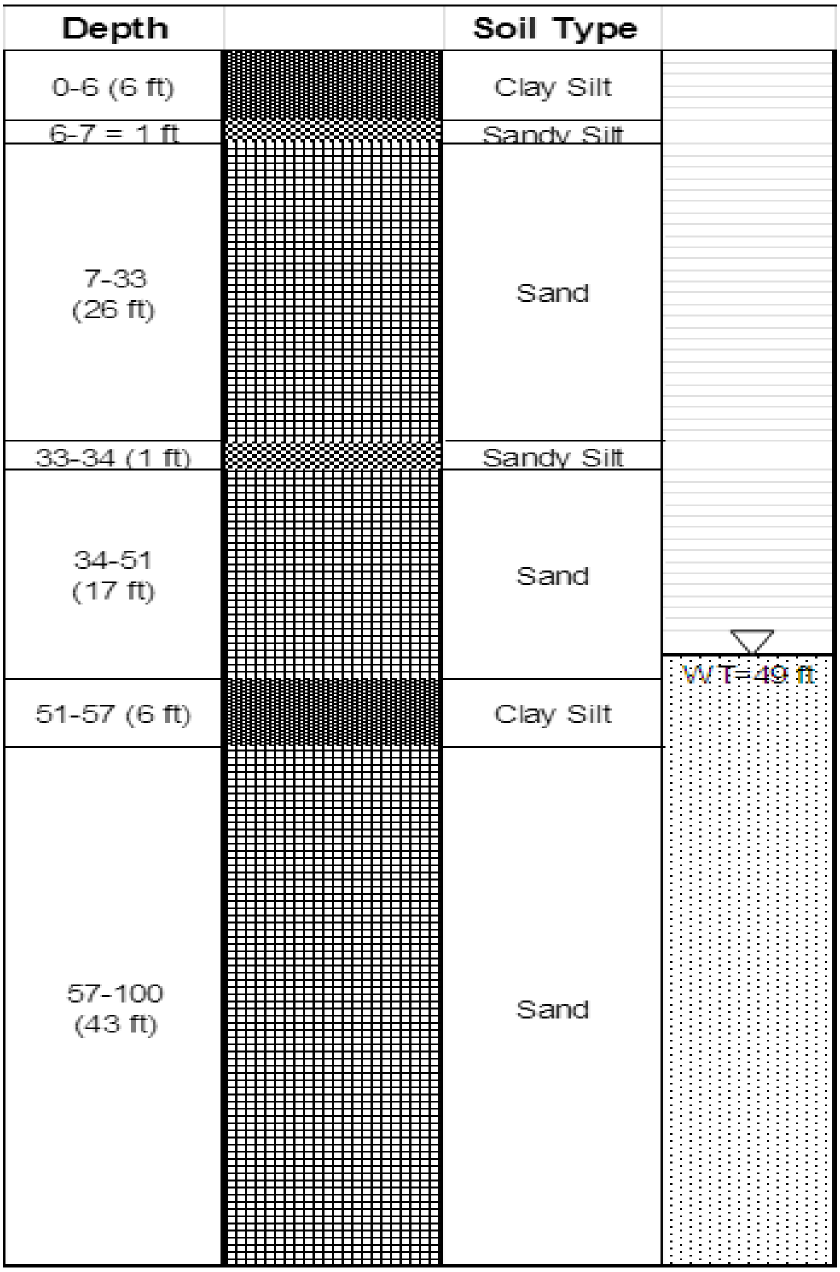

Figure 7. Bore log at Niazbeg Lahore.

3.3. Criteria for Selection of Potential Sites

Initially, groundwater levels and water quality data presented in DLR [23] has been taken as reference for identification of low groundwater levels areas in the Punjab Province. Efforts were made to select the potential sites for conducting the experimentation on artificial recharge on the basis of some scientific reasoning. Keeping in consideration the available data, status of groundwater in the province was reviewed. General criteria for selection of potential sites for installing the exploratory boreholes were set which is given in Table 2.

On the basis of above-mentioned criteria and available data, 60 bore sites were selected for installation of exploratory bore holes for carrying out the field survey and sub-surface investigations. Location of 60 exploratory boreholes installed in Irrigation Zones of (Multan zone 9, Lahore Zone 31, and Faisalabad Zone 20) are shown in Figure 1. Subsequent analysis includes soil strata classification, soil permeability and groundwater flow pattern etc. for selection of potential sites.

Table 2. General criteria for selection of potential sites for artificial recharge.

Sr. No	Parameter	General Value/Limit
i.	Depth to watertable	> 30 ft
ii.	Groundwater Quality (EC)	< 1.5 ds/m
iii.	Average annual rain falls (min)	(Lahore: approx.16")
iv.	Surface water availability	Existing
v.	Ground water extraction	Intensive farmers tubewells
vi.	Soil strata of the area	(min. seepage rate of 10^{-7} cm/sec as in the medium sand strata)
vii.	Water catchment area	Possibly less polluted area
viii.	Staggering of bore hole sites	Along canals (water bodies)
ix.	Field area Characteristics	Depression along canals and wet land within river system

3.4. Potential Sites for Artificial Recharge

On the basis of research and field survey work done so far, 13 potential sites as given in Table 3 and shown in Figure 12 for conducting the actual experimentation on artificial recharge of aquifer have been identified keeping in view the developed criteria outlined in Table 1. These are the potential sites where field experimentation on artificial recharge can be carried out. These are the feasible sites where future investments can be made for sustainable management of groundwater resources in the province.

Table 3. List of potential sites for artificial recharge of aquifer in different irrigation zones.

Sr. #	Name of Site	Possible Recharging Source	Geographical Coordinates	
			Latitude	Longitude
	LAHORE ZONE (Total Bore holes 31)			
i.	Jallo Park, Lahore.	LHR Branch/ BRBD	31.57357 N	74.46995 E
ii.	Along BRBD Canal Right Bank, near Barki Village, Lahore	RD 373+500/ R BRBD Canal	31.47972 N	74.50579 E
iii.	Padhana Village, Barki Road, Lahore (Western Side of Lake).	Rain accumulated depression	31.47519 N	74.62255 E
iv.	Khoo Mian Muzaffar Bodla near Chak No. 47, Pipli Pahar Road, Depalpur	Nehranwala Disty/ Khanwah Br/ BSL-I	30.65165 N	73.55589 E
v.	Post No. 4, Civil Aviation Authority, Southern end of Runway, Lahore International Airport, Lahore	Rain Run-Off	31.50933 N	74.40714 E
vi.	Walton Airport, Ferozepur Road, Lahore.	Rain Run-Off	31.48923 N	74.34890 E
vii.	Northern Plot of Badshahi Mosque, Lahore	Rain Run-Off	31.58960 N	74.31025 E
viii.	Field Research Station, Niazbeg, Multan Road, Lahore.	Roof run-off/ Canal water	31.47464 N	74.22869 E
	MULTAN ZONE (Total bore holes 9)			
ix.	Chak Sooma, Almadina Bricks, Pakpattan	Tabar Minor/PKP Dy./ Khaddar Branch/ PC	30.35718 N	73.41048 E
x.	Bangle Jinan Shah near Rang Shah Pull, Pakpattan	Pakpattan Canal	30.34969 N	73.14286 E
	FAISALABAD ZONE (Total Bore holes 20)			
xi.	Govt. Primary School Saeedabad, Markiz Chiniot Janoobi (near Kot Khuda Yar Rest House), Tehsil & Distt. Chiniot	Chiniot Dist/ Jhang Branch Upper/ LCC	31.66360 N	72.92997 E
xii.	Jaura Rest House at Heads of Feeder Disty and Sultan Pakhra Disty (off-taking RD 37+600 of Bhawana Br), Teh. Bhawana, Distt. Chiniot	Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	31.49978 N	72.72256 E
xiii.	Basic Heath Unit, Chak No. 457 Kot Lakhnana, Gojra Road, Tehsil and Distt. Jhang	Khandwala Mr/ Daular Disty/ JBL/ LCC	31.23375 N	72.41833 E

Few glimpses of potential sites identified for MAR are shown in Figures 8 to 11.

Figure 8. Walton airport Lahore – rainfall water flooding.

Figure 9. A View of flooded Walton Airport Lahore.

Figure 10. A view rainfall water storage in Padhana Lake near Lahore.

Figure 11. A view of rainfall passage of rainfall exist from Badshahi Masjid Lahore.

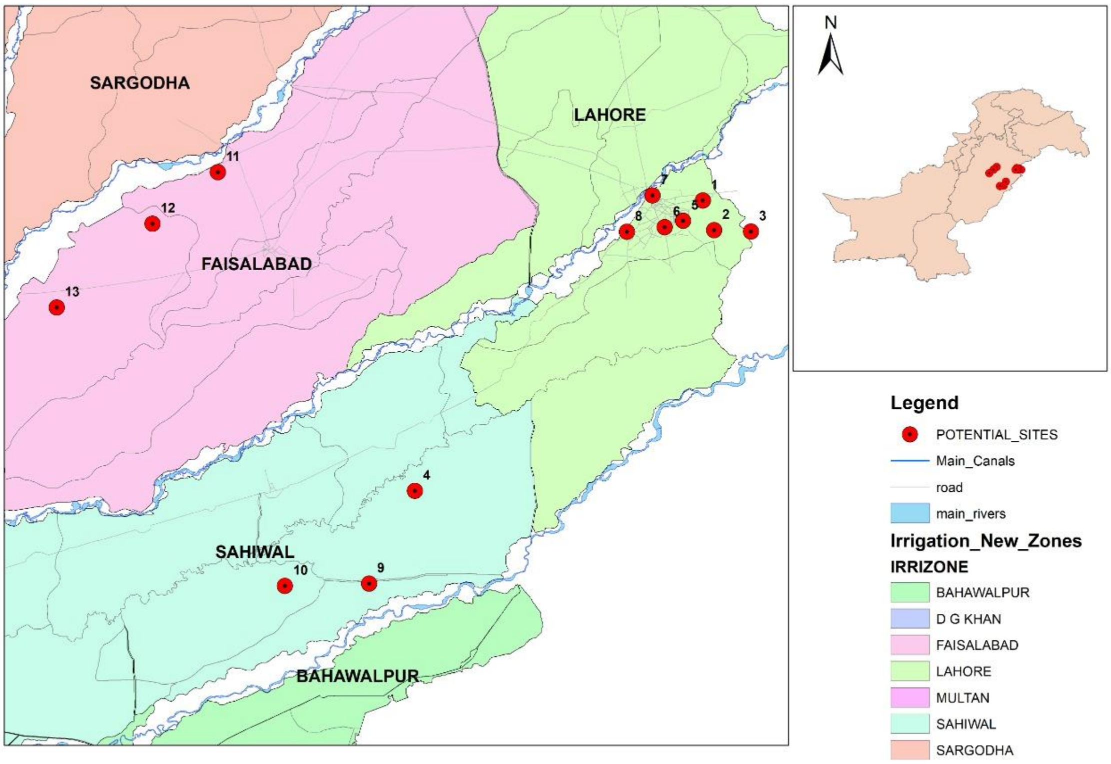

Figure 12. Location of Potential sites.

4. FINDINGS OF THE STUDY

The study, which mainly deals with the preliminary activities like drilling of exploratory bore holes, collection of basic data/available records, installation of piezometers, procurement of equipments, determination of soil and aquifer characteristics, development of a criteria for selection of potential sites for artificial recharge, water availability situation, groundwater quality, depth to watertable, and finally identification of potential sites for actual experimentation on artificial recharge. Out of 60 experimental sites in different irrigation Zones of the Punjab, 13 potential sites have been identified which meet the developed criteria and suitable implementation of small-scale MAR schemes. MAR can be the potential source of augmenting the depleted aquifers at local as well as regional scale. For this purpose, rainfall harvesting and experimentation of artificial recharge on selected potential sites is urgently required. Detailed rainfall-runoff modeling for this purpose is required.

4. ACKNOWLEDGEMENT

The research study has been carried out by Irrigation Research Institute (IRI) under a Provincial Government funded project. Cooperation rendered by different institutions like SMO, IWASRI, IWMI, DLR, WASA, River Survey Division, Drainage Division, Survey of Pakistan, Meteorological department etc. in provision of necessary data/information is acknowledged.

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Annexure A. Groundwater quality results of samples from exploratory borehole in Punjab, Pakistan.

Description		**Ca+ 0.5**	**Mg+ 0.5**	**Na+**	**K+**	**Ca-3 0.5**	**HCO-3**	**Cl-**	**SO-4 0.5**	**NO-3**	**Total Cations**	**Cu**	**Ni**	**Pb**	**Zn**	**pH**	**EC (dS m-1)**	**SAR**	**RSE (mmol L-1)**	**Report for irrigation purposes**
Sample No.	**Site**	**mmol L-1**										**mg L-1**								
1	FRS, Niazbeg, Multan Road, Lahore.	0.5	3.4	14.3	0.1	1.0	3.8	11.4	2.1		18.3	0.04	--	0.008	0.09	8.61	1.792	10.2	0.9	Unfit
2	Sheikh Zaid Islamic Centre on R/S of Lahore Branch, Canal Bank, Lahore.	0.4	0.8	4.1	0.1	T	4.6	0.7	0.1		5.4	0.01	--	--	0.13	8.46	0.562	5.29	3.4	Unfit
3	Jallo Park, Lahore.	1.0	1.9	2.0	0.2	T	4.1	0.8	0.2		5.1	0.02	--	--	0.11	8.5	0.513	1.66	1.2	Fit
4	Shalimar Disty near SOZO Water Park, Lahore.	1.2	2.0	0.5	0.1	T	2.8	0.8	0.2		3.8	0.02	--	0.006	0.10	8.48	0.382	0.39	--	Fit
5	Ravi Syphon, Lahore.	1.6	0.7	0.3	0.1	Nil	2.0	0.6	0.1		2.7	0.01	--	0.005	0.12	8.29	0.271	0.28	--	Fit
6	along BRBD Canal Raight Bank (500 ft. towards West), near Barki Village, Lahore.	0.3	3.1	3.4	0.2	T	4.9	1.4	0.7		7.0	--	--	0.002	0.18	8.67	0.700	2.61	1.5	Fit
7	Padhana Village, Barki Road, Lahore (Western side of Lake).	0.3	2.1	6.4	0.2	0.8	6.1	1.4	0.7		9.0	--	0.006	0.008	0.22	8.92	0.902	5.84	4.5	Unfit
8	Subhar Allah Farm near Allahpur, Depalpur-Bonga Hayat Road, Depalpur	0.5	4.4	20.0	0.3	Nil	7.3	4.0	13.9		25.2	0.03	0.009	0.006	0.14	8.26	2.386	12.8	2.4	Unfit
9	Govt. Primary School Godara, Addah Amli Moti, Depalpur-Bonga Hayat Road, Depalpur.	0.7	3.8	2.6	0.2	T	3.6	1.4	2.3		7.3	--	--	0.003	0.10	8.61	0.731	1.73	--	Fit
10	Khoo Mian Muzaffar Bodla near Chak No. 47, Depalpur.	0.7	2.5	2.6	0.2	Nil	3.9	1.6	1.5		6.0	--	--	--	0.08	8.31	0.602	2.37	--	Fit
11	Dera Milik Abbas Khokhar, Village Pipli Pahar, Depalpur.	1.9	4.1	7.7	0.3	Nil	0.4	5.8	7.8		14.0	0.01	--	--	0.05	8.29	1.402	4.44	--	Fit
12	Dera Khalid Hanif Bodla, Chak No. 48-D, Depalpur.	0.4	2.7	2.7	0.2	T	2.6	0.9	2.5		6.0	0.01	--	--	0.07	8.58	0.602	2.17	--	Fit
13	Dera Muhammad Tufail Punwari near 38-D Kalan, Shergarh-Depalpur Road, Depalpur.	0.7	2.4	2.1	0.2	T	2.7	1.0	1.7		5.4	0.01	--	--	0.09	8.31	0.540	1.35	--	Fit

14	Village 63-D, Mauza Bonga Hayat, Depalpur.	2.1	4.7	18.0	0.3	Nil	8.0	5.7	11.4	25.1	0.01	--	--	0.13	8.12	2.461	9.76	1.2	Unfit
15	Dera Sultan Wattoo, Chak Watooan near Village 38-D, Okara-Depalpur Road, Depalpur.	1.2	2.5	1.1	0.2	Nil	2.7	1.2	1.1	5.0	0.01	--	--	0.18	8.20	0.502	0.81	--	Fit
16	Govt. Primary School, Chak Chota Bedi (Khurd), Bonga Hayat-Pakpattan Road, Bonga Hayat.	0.9	2.5	2.8	0.2	T	3.4	1.4	1.6	6.4	0.02	--	--	0.14	8.47	0.641	2.15	--	Fit
17	Govt. High School, Kumari Wala Village near Pakpattan.	1.0	9.3	16.3	0.3	T	3.2	5.2	18.5	26.9		--	0.006	0.08	8.43	2.540	7.18	--	Unfit
18	Govt. Girls Elementary School, Chak Noor Muhammad near Village 11-SP, Pakpattan.	1.9	4.4	4.0	0.3	T	2.7	1.7	6.2	10.6		--	0.003	0.08	8.39	1.063	2.25	--	Fit
19	Dera Afzal Khan, Village 17-SP, Pakpattan.	0.9	2.4	1.7	0.2	T	2.9	1.0	1.3	5.2	0.009	--	0.003	0.05	8.42	0.521	1.32	--	Fit
20	Bongiwal Grid Station (132-KV) Bhogiwal), Bund Road, Lahore.	5.6	7.0	16.6	0.3	Nil	9.4	13.4	6.7	29.5	0.03	0.008	0.005	0.11	7.82	2.864	6.61	--	Unfit
21	Ravi Grid Station (220-KV), Bund Road, Lahore.	0.8	1.5	2.5	0.1	T	2.7	1.3	0.9	4.9	--	--	--	0.07	8.38	0.411	2.33	0.4	Fit
22	Post No. 4, Civil Aviation Authority, Southern End of Runway Lahore International Airport, Lahore.	0.2	2.4	12.3	0.1	2.0	8.2	1.7	3.1	15.0	0.005	--	0.003	0.06	9.03	1.493	10.8	7.6	Unfit
23	Walton Airport, Ferozepur Road, Lahore.	0.1	2.9	17.0	0.1	3.0	10.5	1.8	4.8	20.1	0.01	--	--	0.05	9.21	1.908	13.9	10.5	Unfit
24	Defence Public School for Boys, R-Block, Phase-II, DHA, Lahore.	0.6	4.2	6.4	0.3	T	5.9	1.1	4.5	11.5	0.006	--	--	0.08	8.43	1.152	4.13	1.1	Fit
25	Defence Degree College for Women, Sector-FF, Phase-IV, DHA, Lahore.	0.5	3.2	8.0	0.2	0.8	4.9	1.2	5.0	11.9	--	--	--	0.04	8.75	1.201	5.88	2.0	Fit
26	Flora Park, Sector-X, Phase-III, DHA, Lahore.	0.4	2.2	15.7	0.2	1.8	8.8	2.7	5.2	18.5	--	--	--	0.03	9.07	1.793	13.8	6.2	Unfit
27	Public Park, Sector-P, Phase-1, DHA, Lahore.	0.4	2.1	15.3	0.2	2.4	9.3	3.6	2.7	18.0	0.006	--	0.005	0.08	9.1	1.726	13.7	6.8	Unfit

28	Out-Let of Harpalke Minor, Phase-IV, DHA, Lahore.	0.6	3.7	0.5	0.2	T	4.0	0.8	0.2	5.0	0.007	0.006	0.008	0.12	8.45	0.502	0.34	--	Fit
29	Northern Plot of Badshahi Mosque, Lahore.	2.3	2.3	1.9	0.1	Nil	4.1	0.8	1.7	6.6	--	0.007	--	0.09	7.93	0.661	1.25	--	Fit
30	Chak Sooma, Almadina Bricks, Pakpattan.	0.5	3.8	10.0	0.1	Nil	6.2	2.1	6.1	14.4	--	--	--	0.05	8.32	1.443	6.82	1.9	Fit
31	Govt. Primary School, Mauza Pacca Sidhar, Pakpattan.	0.4	3.4	5.6	0.1	T	4.7	1.1	4.2	10.0	0.008	--	--	0.07	8.48	1.020	3.82	0.9	Fit
32	Govt. High School, Chak Azmat, Pakpattan.	2.2	4.9	2.4	0.2	T	4.4	1.0	4.3	9.7	--	--	--	0.09	8.39	0.972	1.27	--	Fit
33	Dera Tauqeer Hussain Shah, Nazim Chak Shafi, Pakpattan.	1.3	3.8	4.9	0.3	Nil	2.4	1.9	6.0	10.3	--	--	--	0.13	8.31	0.103	3.07	--	Fit
34	Govt. Boys School, Village 50-SP, Pakpattan.	2.3	2.6	1.7	0.1	Nil	3.5	2.2	1.0	6.7	--	--	--	0.08	8.16	0.671	1.09	--	Fit
35	Bangla Jiwan Shan, Pakpattan.	1.7	3.8	2.1	0.1	Nil	2.5	0.8	4.4	7.7	0.008	--	--	0.11	8.19	0.772	1.27	--	Fit
36	Govt. Primary School, Village Heera Sing, Pakpattan.	1.0	4.5	9.8	0.1	Nil	3.5	2.0	9.9	15.4	--	--	--	0.05	8.3	1.528	6.14	--	Unfit
37	Village Mahi-wala Khoo, Pakpattan.	3.6	2.6	4.4	2.4	Nil	3.1	1.6	8.3	13.0	0.01	--	--	0.03	7.92	1.303	2.50	--	Fit
38	Govt. Middle School, Village 32-SP, Pakpattan.	1.8	1.8	1.9	0.3	Nil	2.5	0.9	2.4	5.8	--	--	--	0.05	8.12	0.581	1.42	--	Fit
39	Govt. Primary School Saeedabad, Markiz Chiniot Janoobi (near Kot Ahmad Yar Rest House), Tehsil & Distt. Chiniot.	3.3	3.9	2.2	0.2	Nil	4.9	1.2	3.5	9.6	--	--	--	0.07	8.1	0.962	1.16	--	Fit
40	Dera Muhammad Imtiaz S/o Dost Muhammad, Chak No. 132/JB Dhamroy, Tehsil & Distt. Chiniot.	1.5	5.7	1.2	0.4	Nil	6.6	0.8	1.4	8.8	--	--	--	0.10	8.22	0.883	0.63	--	Fit
41	Dera Mehr Ghulam Muhammad S/o Sikandar, Mauza Aidlana, Tehsil & Distt. Chiniot.	1.9	2.9	2.8	0.2	Nil	4.5	1.1	2.2	7.8	--	--	--	0.06	8.11	0.780	1.81	--	Fit
42	Dera Qasim Ali, Chak No. 138/JB Noul, Tehsil & Distt. Chiniot.	2.3	5.0	3.3	0.2	Nil	5.1	2.0	3.7	10.8	--	--	--	0.09	8.17	1.084	1.73	--	Fit

43	Dera Mian Ghulam Shabbir S/o Mian Noor Nabi, Mouza Barkhurdar, Gaddianwala Pull, Bhawana-Chiniot Road, Tehsil & Distt. Chiniot.	2.7	2.7	1.7	0.2	Nil	5.7	1.4	0.2	7.3	--	--	--	0.05	7.68	0.731	1.03	0.3	Fit
44	Chak No. 223/JB (Shumali), Ramana, Bhawana-Panseera Road, Tehsil Bhawana, Distt. Chiniot.	1.5	3.7	0.4	0.8	T	4.8	0.5	1.1	6.4	--	--	--	0.08	8.36	0.640	0.25	--	Fit
45	Veterinary Hospital, Chak no. 199/JB Rahmoana, Tehsil Bhawana, Distt Chiniot.	1.3	4.0	7.5	0.4	T	6.8	2.8	2.6	12.2	--	--	--	0.11	8.34	1.221	4.61	1.5	Fit
46	Dera Shumsul Haq S/o Karam Ali Sipra, Chak No. 159/JB Wer Siprawan, Tehsil & Distt. Jhang.	1.9	3.7	2.5	0.2	T	6.5	1.0	0.8	8.3	--	--	--	0.08	8.32	0.830	1.49	0.9	Fit
47	Dera Ghulam Muhammad Jappa, Chak No. 196/JB (Jeewan Ka Chak) near Adilwala Rest House, Trhsil Bhawana, Distt. Chiniot.	2.7	2.3	0.6	0.2	Nil	3.7	0.5	1.6	5.8	--	--	--	0.06	8.17	0.583	0.38	--	Fit
48	Dera Munshi Ghulam Akbar Bharwana, Chak No. 261/JB Kot Humayun, Tehsil and Distt, Jhang.	1.6	2.5	2.2	0.2	Nil	3.8	1.2	1.5	6.5	--	--	--	0.04	8.14	0.652	1.54	--	Fit
49	Jaura Rest House at Heads of Feeder Disty and Sultan Pakhra Disty (off-taking RD 37+600 of Bhawana Br.) The. And Distt. Chiniot.	1.0	1.7	0.3	0.2	Nil	2.6	0.4	0.2	3.2	--	--	--	0.07	8.19	0.321	0.26	--	Fit
50	Dera Manzoor Hussain S/o Bahadar (Cheera), Chak No. 242/JB, Mauza Sir Nanga, Bhawana-Panseera Road, Tah. Bhawana, Distt. Chiniot.	2.0	4.1	5.7	0.2	Nil	7.7	0.9	3.4	12.0	--	--	--	0.09	8.07	1.120	3.26	1.6	Fit

51	Dera Muhammad Yar S/o Haji Khan Muhammad Mahra (adjioning abadi), Bhawana Road, The. Bhawana, Distt. Chiniot.	0.8	5.1	8.8	0.3	T	5.1	2.1	7.8	15.0	--	--	--	0.08	8.36	1.493	5.12	--	Fit
52	Dera Ahmad Nawaz S/o Abdullah Dehlera, Mauza Suleman Kallar Wala, Sherabad Stop, Tehsil and Distt. Jhang.	0.3	3.4	5.7	0.2	T	3.8	4.4	1.4	9.6	0.007	--	--	0.12	8.39	0.959	4.19	0.1	Fit
53	Dera Zulfiqar Bhoogia, Chak No. 181 Bhogia (6-km from Gojra More), Jhang-FSD Road, Tehsil and Distt. Jhang.	1.9	3.5	7.8	0.3	Nil	6.2	1.8	5.5	13.5	--	--	--	0.15	8.1	1.346	4.75	0.8	Fit
54	Dera Mian Saifullah S/o Ghulam Muhammad, Chak No. 269/JB Kikranwala, Jhang-FSD Road, Tahsil and Distt. Jhang.	2.3	2.1	4.6	0.2	Nil	2.4	2.6	4.2	9.2	--	--	--	0.13	7.98	0.922	3.10	--	Fit
55	Basic Health Unit, Chak No. 457 Kot Lakhnana, Gojra Road, Tehsil and Distt. Jhang.	1.9	6.1	3.5	0.6	Nil	8.1	1.4	2.6	12.1	--	--	--	0.09	8.03	1.213	1.75	0.1	Fit
56	Chak No. 448 Hirajanwala (near outlet No. 63+645/L, Daular Disty), Jhang-FSD Road, Adda Mochiwala, Tehsil and Distt. Jhang.	1.2	2.7	1.1	0.2	Nil	4.1	1.0	0.1	5.2	--	--	--	0.07	8.09	0.522	0.81	0.4	Fit
57	Dera Alam Zaib S.o Gohar Rehman, Nazim UC-49, Chak No. 475 Syedwala, Jhang-Toba Road, Tehsil and Distt. Jhang.	0.7	1.7	12.3	0.2	Nil	5.1	2.1	7.7	14.9	--	--	--	0.06	8.23	1.493	11.2	2.7	Unfit
58	Dera Tariq Javed, Mauza Lakh Badhar, Jhang-Mudduki Road, Tehsil and Distt. Jhang.	3.7	6.3	19.5	0.3	Nil	5.5	10.9	13.4	29.8	--	--	--	0.03	8.02	2.813	8.72	--	Unfit

Annexure B. Depth to water table data of exploratory boreholes in Lahore Irrigation Zones, Punjab, Pakistan.

Sr. #	Site Description	Recharging Source/ Reference	Bore Dug (No.)	Bore Completion Date	Depth to Water Table (at the time of Boring) (Ft)	Depth to Water Table (ft) 2009				Depth to Water Table (ft) 2010				Remarks
						Pre-Monsoon -2009		Post-Monsoon -2009		Pre-Monsoon -2010		Post-Monsoon -2010		
						Date	Level	Date	Level	Date	Level	Date	Level	
1	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Lahore Zone													
1	Field Research Station, Niazbeg, Multan Road, Lahore.	Roof Run-Off	1	17/02/2009	49	13-06-09	51.43	4/11/2009	51.97	10/5/2010	54.33			GW unfit for irrigation (DLR Report of Sep, 2009)
2	Sheikh Zaid Islamic Center on R/S of Lahore Branch, Canal Bank, Lahore.	LHR Branch	1	18/02/2009	95	13-06-09	>100	4/11/2009	97.67	26/06/2010	>100			GW unfit for irrigation (DLR Report of Sep, 2009)
3	Jallo Park, Lahore.	LHR Branch	1	21/02/2009	47	11/6/2009	49.86	6/11/2009	50.75	26/06/2010	54.297			GW fit for irrigation
4	Shallimar Disty, near Sozo Water Park, Lahore	Shalimar Disty/ BRBD	1	21/02/2009	36	11/6/2009	37.82	6/11/2009	36.15	26/06/2010	41.7			GW fit for irrigation
5	Ravi Syphon, Lahore	BRBD Canal	1	22/02/2009	20	11/6/2009	23.03	6/11/2009	15.17					GW fit for irrigation
6	Along BRBD Canal Right Bank, near Barki Village, Lahore	RD 373+500/ R BRBD Canal	1	23/02/2009	26	11/6/2009	27.72	6/11/2009	28	19-06-10	30.35			GW fit for irrigation
7	Along BRBD Canal Right Bank (500 ft towards West), near Barki Village, Lahore	RD 373+500/ R BRBD Canal	1	23/02/2009	20	11/6/2009	21.71	6/11/2009	22.17	19-06-10	23.78			GW fit for irrigation
8	Padhana Village, Barki Road, Lahore (Eastern Side of Lake).	Rain accumulated depression	1	25/02/2009	30	11/6/2009	33.32	6/11/2009	35.33	25-06-10	35.66			GW unfit for irrigation

9	Padhana Village, Barki Road, Lahore (Western Side of Lake).	Rain accumulated depression	1	25/02/2009	32	11/6/2009	34.77	6/11/2009	37.43	25-06-10	37.89	(DLR Report of Sep, 2009)
10	Subhan Allah Farm, near Allahpur, Depalpur-Bonga Hayat Road, Depalpur.	Probynabad Minor/ Depalpur Disty/ Khanwah Branch	1	3/3/2009	56	2/7/2009	58.9	2/11/2009	55.61	2/7/2010	60.2	GW unfit for irrigation (DLR Report of Sep, 2009)
11	Govt. Primary School Godara, Addah Amli Moti, Depalpur-Bonga Hayat Road, Depalpur	Probynabad Minor/ Depalpur Disty/ Khanwah Branch	1	4/3/2009	59	2/7/2009	62.22	2/11/2009	58.2	2/7/2010	62.93	GW fit for irrigation
12	Khoo Mian Muzaffar Bodla Near Chak No. 47, Pipli Pahar Road, Depalpur	Nehranwala Disty/ Khanwah Branch	1	5/3/2009	46	2/7/2009	49.13	2/11/2009	49.75	2/7/2010	53.81	GW fit for irrigation
13	Dera Malik Abbas Khokhar, Village Pipli Pahar, Depalpur	Alwardi Minor/ Nehranwala Disty	1	5/3/2009	42	2/7/2009	44.93	2/11/2009	44.53	2/7/2010	47.28	GW fit for irrigation
14	Dera Khalid Hanif Bodla, Chak No. 48-D, Pipli Pehar Road, Depalpur	Alwardi Minor/ Nehranwala Disty	1	12/3/2009	38	2/7/2009	41.36	2/11/2009	37.47	2/7/2010	43.01	GW fit for irrigation
15	Dera Muhammad Tufail Punwari, Near 38-D Kalan, Shergarh-Depalpur Road, Depalpur	Qila Jawind Sing Mr/ Nehranwala Disty	1	12/3/2009	32	2/7/2009	34.34	2/11/2009	33.46	2/7/2010	36.35	GW fit for irrigation
16	Village 63-D, Mauza Bonga Hayat, Depalpur	Gobindpur Minor/ Depalpur Disty	1	13/03/2009	56	2/7/2009	58.15	2/11/2009	58.73	2/7/2010	60.14	GW unfit for irrigation (DLR Report of Sep, 2009)
17	Dera Sultan Wattoo,	Qila Jawind Sing Mr/	1	14/03/2009	40	2/7/2009	42.12	2/11/2009	40.09	2/7/2010	Choked at 39.83	GW fit for irrigation

	Chak Wattooan near Village 38-D, Okara-Depalpur Road, Depalpur	Nehranwala Disty										
18	Govt. Primary School, Thatta Rangran/Chak Chota Bedi, Bonga Hayat - Pakpattan Road, Bonga Hayat	Nanak Disty/ Wanga Disty/ LDC	1	18/03/2009	56	2/7/2009	59.82	2/11/2009	60.3	2/7/2010	61.35	GW fit for irrigation
19	Govt. High School, Kumari Wala Pakpattan	Atta Minor/ PKP Canal	1	18/03/2009	47	2/7/2009	48.41	2/11/2009	48.59	2/7/2010	50.46	GW unfit for irrigation (DLR Report of Sep, 2009)
20	Govt. Girls Elementary School 11/SP, Chak Noor Muhammad, Pakpattan	Atta Minor/ PKP Canal	1	1/4/2009	44	2/7/2009	46.67	2/11/2009	44.59	2/7/2010	Choked at 46.83	GW fit for irrigation
21	Dera Afzal Khan, Village 17-SP, Pakpattan	Sohag Disty/ Wanga Disty/ LDC	1	4/4/2009	60	2/7/2009	63.63	2/11/2009	61.68	2/7/2010	64.12	GW fit for irrigation
22	Bhogiwal Grid Station (132 KV), Bund Road, Lahore.	For pollution assessment	1	15/04/2009	50	13-06-09	53.69	7/11/2009	54.3			GW unfit for irrigation (DLR Report of Sep, 2009)
23	Ravi Grid Station (220-KV), Bund Road, Lahore.	-do-	1	15/04/2009	27	13-06-09	29.91	7/11/2009	32.77			GW fit for irrigation
24	Post No. 4, Civil Aviation Authority, Southern end of Runway, Lahore International Airport	Rain Run-Off	1	16/04/2009	69	11/6/2009	71.73	6/11/2009	73.46	18-06-10	75.75	GW unfit for irrigation (DLR Report of Sep, 2009)

25	Walton Airport, Ferozepur Road, Lahore.	Rain Run-Off	1	21/04/2009	>100	13-06-09	>100.0	6/11/2009	>100.0	25-06-10	>100.0	GW unfit for irrigation (DLR Report of Sep, 2009)
26	Defence Public School for Boys, R-Block, DHA Phase-II, Lahore.	Roof Run-Off	1	24/04/2009	66	11/6/2009	68.35	6/11/2009	70.08	25-06-10	72.34	GW fit for irrigation
27	Defence Degree College for Women, Sector-FF, Phase-IV, DHA, Lahore.	Roof Run-Off	1	24/04/2009	73	11/6/2009	75.54	6/11/2009	77.66	19-06-10	80.31	GW fit for irrigation
28	Flora Park, Sector-X, Phase-III, DHA, Lahore	Roof Run-Off	1	26/04/2009	82	11/6/2009	>84.00	6/11/2009	96.75	19-06-10	91.14	GW unfit for irrigation (DLR Report of Sep, 2009)
29	Public Park, Sector-P, Phase-I, DHA, Lahore	Roof Run-Off	1	27/04/2009	68	11/6/2009	69.63	6/11/2009	70.83	19-06-10	72.57	GW unfit for irrigation (DLR Report of Sep, 2009)
30	Out-Let of Harpalke Minor, Phase-VI, DHA, Lahore.	Khaira Disty/ BRBD	1	29/04/2009	36	11/6/2009	36.08	6/11/2009	35.83	19-06-10	38.91	GW fit for irrigation
31	Northern Plot of Badshahi Mosque, Lahore	Rain Run-Off	1	19/06/2009	63	29-06-09	65.6	7/11/2009	65.81			GW fit for irrigation
	TOTAL (LHR ZONE)		31									
	Multan Zone											
1	Chak Sooma, Almadina Bricks, Pakpattan	Tabar Minor/PKP Dy/ Khadir Branch/ PC	1	4/4/2009	48	2/7/2009	51.17	3/11/2009	50.23	2/7/2010	53.64	GW fit for irrigation
2	Govt. Primary School,		1	5/4/2009	51	3/7/2009	54.87	3/11/2009	55.25	3/7/2010	Choked at 56.02	GW fit for irrigation

	Mauza Pacca Sidhar, Pakpattan	Pakpattan Disty/ Khadir Br/ PC										
3	Govt. High School, Chak Azmat, Pakpattan	Pakpattan Disty/ Khadir Branch/ PC	1	6/4/2009	52	3/7/2009	54.94	3/11/2009	55.74	3/7/2010	56.92	GW fit for irrigation
4	Dera Tauqeer Hussain Shah, Nazim Chak Shafi, Pakpattan	Salim Kot Disty/ PC	1	8/4/2009	53	3/7/2009	55.76	3/11/2009	56.53	3/7/2010	57.68	GW fit for irrigation
5	Govt. Boys Primary School, 50-SP, Pakpattan	Salim Kot Disty/ PC	1	8/4/2009	50	3/7/2009	53.49	3/11/2009	54.88	3/7/2010	55.58	GW fit for irrigation
6	Bangla Jiwan Shah near Rang Shah Pull, Pakpattan	Pakpattan Canal	1	8/4/2009	49	3/7/2009	52.8	3/11/2009	53.97	3/7/2010	55.08	GW fit for irrigation
7	Govt. Primary School, Village Kot Heera Sing, Pakpattan	Shafi Disty/ PC	1	8/4/2009	52	3/7/2009	Q	3/11/2009	Choked at 40 ft depth	3/7/2010	Choked at 39.25	GW unfit for irrigation (DLR Report of Sep, 2009)
8	Village Mahi-wala Khoo, Adda More Singh, Pakpatan	Shafi Disty/ PC	1	9/4/2009	56	3/7/2009	Choked at 35 ft depth	3/11/2009	Choked at 35 ft depth	3/7/2010	Choked at 34.75	GW fit for irrigation
9	Govt. Boys Elementary School, 32-SP, Pakpattan (Part Primary)	Salim Kot Disty/ PC	1	10/4/2009	59	3/7/2009	62.32	3/11/2009	63.02	3/7/2010	61.22	GW fit for irrigation
	TOTAL (Multan Zone)		9									
Grand Total	Total (LHR & MTN Zone)		40									

Annexure C. Depth to water table data of Faisalabad irrigation Zone in Punjab Pakistan.

Sr. #	Site Description	Recharging Source/ Reference	Bore Dug (No.)	Bore Completion Date	Depth to Water Table (at the time of Boring) (Ft)	Depth to Water Table (ft)				Depth to Water Table (ft)				Remarks
						Pre-Monsoon -2009		Post-Monsoon -2009		Pre-Monsoon -2009		Post-Monsoon -2009		
						Date	Level	Date	Level	Date	Level	Date	Level	
1	3	4	5	6	7	8	9	10	11					13
	Faisalabad Zone													
1	Govt. Primary School Saeedabad, Markiz Chiniot Janoobi (near Kot Khuda Yar Rest House), Tehsil and Distt. Chiniot	Chiniot Dist/ Jhang Branch Upper/ LCC	1	2/6/2009	47	6/7/2009	47.6	12/10/2009	47.24	19/06/2010	49.25			GW fit for irrigation
2	Dera Muhammad Imtiaz S/O Dost Muhammad, Chak No. 132/ JB Dhamroy, Tehsil and Distt. Chiniot	Pabbarwala Disty/ JBU/ LCC	1	3/6/2009	39	6/7/2009	40.7	12/10/2009	41.37	19/06/2010	42.89			GW fit for irrigation
3	Dera Mehr Ghulam Muhammad S/O Sikandar, Mauza Aidlana, Teh. Bhawana, Distt. Chiniot	Chiniot Dist/ JBU/ LCC	1	4/6/2009	49	6/7/2009	49.4	12/10/2009	49.83	19/06/2010	50.48			GW fit for irrigation
4	Dera Qasim Ali, Chak No. 138/ JB Noul, Tehsil and Distt. Chiniot	Kot Ahmad Yar Br/ Chiniot Dist/ JBU/ LCC	1	4/6/2009	47	6/7/2009	48.6	12/10/2009	49.11	19/06/2010	50.06			GW fit for irrigation
5	Dera Mian Ghulam Shabbir S/O Mian Noor Nabi, Mauza Barkhurdar,	Taja Berwala Minor/ Ahmad Yar	1	5/6/2009	50	7/7/2009	51.3	30/10/2009	52.49	19/06/2010	52.79			GW fit for irrigation

	Gaddianwala Pull, Bhawana-Chioniot Road, Teh. Bhawana, Distt. Chiniot	Br/ Chiniot Dist/ JBU/ LCC										
6	Chak No. 223/ JB (Shumali), Ramana, Bhawana - Panseera Road, Teh. Bhawana, Distt. Chiniot	Mochiwala Br. Disty/ Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	1	5/6/2009	49	7/7/2009	50.9	12/10/2009	51.74	11/6/2010	53.29	GW fit for irrigation
7	Veterinary Hospital, Chak No. 199/ JB Rahmoana, Teh. Bhawana, Distt. Chiniot	Nila Minor No. 1/ JBL/ LCC	1	5/6/2009	46	7/7/2009	46.7	12/10/2009	47.75	13/06/2010	Choked at 46.42	GW fit for irrigation
8	Dera Shamsul Haq S/O Karam Ali Sipra, Chak No. 159/ JB Wer Siprawan, Tehsil and Distt. Jhang	Maghani Disty/ Feeder Disty/ Bhawana Br/ JBU(T)/ LCC	1	6/6/2009	45	7/7/2009	45.4	30/10/2009	45.47	11/6/2010	46.75	GW fit for irrigation
9	Dera Ghulam Muhammad Jappa, Chak No. 196/ JB (Jeewan ka Chak) near Adilwala Rest House, Teh. Bhawana, Distt. Chiniot	Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	1	7/6/2009	54	7/7/2009	55.5	30/10/2009	55.9	11/6/2010	56.46	GW fit for irrigation
10	Dera Munshi Ghulam Akbar Bharwana, Chak No. 261/ JB Kot Humayun, Tehsil and Distt. Jhang	Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	1	7/6/2009	55	7/7/2009	56.35	30/10/2009	56.82	19/06/2010	57.67	GW fit for irrigation
11	Jaura Rest House at Heads of Feeder Disty and Sultan Pakhra Disty (off-	Sultan Pakhra Disty/ Bhawana	1	11/6/2009	38	6/7/2009	39.9	12/10/2009	40.06	11/6/2010	42.38	GW fit for irrigation

	taking RD 37+600 of Bhawana Br), Teh. Bhawana, Distt. Chiniot	Br/ JBU (T)/ LCC										
12	Dera Manzoor Hussain S/O Bahadar (Cheera), Chak No. 242/ JB, Mauza Sir Nanga, Bhawana -Panseera Road, Teh. Bhawana, Distt. Chiniot	Feeder Disty/ Bhawana Br/ JBU (T)/ LCC	1	11/6/2009	49	7/7/2009	Choked at 30 ft	12/10/2009	Choked at 37 ft			GW fit for irrigation
13	Dera Muhammad Yar S/O Haji Khan Muhammad Mahra (adjoining abadi), Chak No. 235/ JB Hibbuana, Bhawana Road, Teh. Bhawana, Distt. Chiniot	Hibbuana Disty/ Bhawana Br/ JBU (T)/ LCC	1	12/6/2009	35	6/7/2009	36.8	12/10/2009	37.3	11/6/2010	38.75	GW fit for irrigation
14	Dera Ahmad Nawaz S/O Abdullah Dehlera, Mauza Suleman Kallar Wala, Sherabad Stop, Tehsil and Distt. Jhang	Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	1	12/6/2009	51	7/7/2009	53.3	30/10/2009	52.69	13/06/2010	53.79	GW fit for irrigation
15	Dera Zulfiqar Bhogia, Chak No. 181 Bhogia (6 km from Gojra More), Jhang - FSD Road, Tehsil and Distt. Jhang	Balluana Mr/ Daular Disty/ JBL/ LCC	1	13/06/2009	42	7/7/2009	43	30/10/2009	43.3	13/06/2010	44.75	GW fit for irrigation
16	Dera Mian Saifullah S/O Ghulam Muhammad, Chak No. 269/ JB Kikranwala, Jhang - FSD Road,	Jhang Mr/ Sultan Pakhra Disty/ Bhawana Br/ JBU (T)/ LCC	1	13/06/2009	55	7/7/2009	56.9	30/10/2009	56.99	12/6/2010	57.46	GW fit for irrigation

	Tehsil and Distt. Jhang											
17	Basic Heath Unit, Chak No. 457 Kot Lakhnana, Gojra Road, Tehsil and Distt. Jhang	Khandwala Mr/ Daular Disty/ JBL/ LCC	1	15/06/2009	45	7/7/2009	46.1	30/10/2009	46.17	13/06/2010	40.39	GW fit for irrigation
18	Chak NO. 448 Hirajanwala (near Outlet NO. 63+645/ L, Daular Disty), Jhang - FSD Road, Adda Mochiwala, Tehsil and Distt. Jhang	Daular Disty/ JBL/ LCC	1	15/06/2009	30	7/7/2009	30.7	30/10/2009	30.41	13/06/2010	32.63	GW fit for irrigation
19	Dera Alam Zaib S/O Gohar Rehman, Nazim UC-49, Chak No. 475 Syedwala, Jhang-Toba Road, Tehsil and Distt. Jhang	Daular Disty/ JBL/ LCC	1	16/06/2009	40	7/7/2009	39.5	30/10/2009	39.76	20/06/2010	40.92	GW unfit for irrigation (DLR Report of Sep, 2009)
20	Dera Tariq Javed, Mauza Lakh Badhar, Jhang - Mudduki Road, Tehsil and Distt. Jhang	Lakh Badhar Mr/ Daular Disty/ JBL/ LCC	1	16/06/2009	41	7/7/2009	41.7	30/10/2009	42.52	12/6/2010	42.58	GW unfit for irrigation (DLR Report of Sep, 2009)
	Total (FSD Zone)		20									