EVALUATION OF ABANDONED WELLS FOR GROUNDWATER RECHARGE

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF TECHNOLOGY
in
SOIL AND WATER ENGINEERING
(Minor Subject: Soil Science)**

By

**Palwinder Singh
L-2K13/14-AE-191-M**

**Department of Soil and Water Engineering
College of Agricultural Engineering and Technology**
© PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA-141004

2017

CERTIFICATE I

This is to certify that the thesis entitled, **"Evaluation of Abandoned Wells for Groundwater Recharge"** submitted for the degree of **M-Tech,** in the subject of **Soil and Water Engineering** (Minor Subject: **Soil Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Palwinder Singh (L-2013/14-AE-191-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

(Dr. Rajan Aggarwal)
Major Advisor
Senior Research Engineer-Cum-Head
Department of Soil and Water Engineering
Punjab Agricultural University
Ludhiana-141 004

CERTIFICATE II

This is to certify that the dissertation entitled, **“Evaluation of Abandoned Wells for Groundwater Recharge”** submitted by **Palwinder Singh** (Admn No. **L-2013/14-AE-191-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M-Tech.** in the subject of **Soil & Water Engineering** (Minor subject: **Soil Science**) has been approved by the Student’s Advisory Committee along with the External Examiner after an oral examination on the same.

____
Major Advisor
Dr. Rajan Aggarwal

____
External Examiner
Dr. Satyendra Kumar
Principal Scientist
CSSRI, Karnal-132001, Haryana.

____
Head of the Department
Dr. Rajan Aggarwal

____
Dean, Post-Graduate Studies
Dr. (Mrs) Neelam Grewal

ACKNOWLEDGEMENT

I express my deep sense of gratitude and indebtedness to my esteemed major advisor, Dr. Rajan Aggarwal, Senior Research Engineer-Cum-Head, Department of Soil and Water Engineering for his valuable guidance, constructive criticism and incessant encouragement during the course of my work and critical scrutiny of this manuscript which led to the successful completion of this study.

I wish to extend my heartiest thanks all the members of my advisory committee namely Dr. Samanpreet Kaur, Assistant Research Engineer, Department of Soil and Water Engineering, Dr. M. S. Hadda, Professor, Department of Soil Science and Dr. Sunil Garg, Senior Research Engineer, Department of Soil and Water Engineering (Dean PGS Nominee) for their help, guidance and valuable suggestions during the course of this research work. I am also thankful to 'Groundwater Resource Management to Mitigate the Impact of Climate Change in Punjab and Haryana' funded by National Innovations in Climate Resilient Agriculture (NICRA), for providing necessary facilities to carry out my research work.

I am also grateful to Dr. Neelam Grewal, Dean PGS, PAU, Ludhiana. I take this opportunity to express sincere reverence, deep sense of gratitude and grateful thanks to all the faculty members of Soil and Water Engineering, PAU, Ludhiana.

I express heartiest thanks to Er. Mandeep Singh Brar and others members of the technical and non-teaching staff of Department of Soil and Water Engineering for their help in experimental work.

It gives me immense pleasure and very special feelings to acknowledge my respected parents Mr. Ranjit Singh, Mrs. Manpreet Kaur and I wish to my deep appreciation to my friends Mr. Puneet Sharma and Mr. Harjinder Singh for their moral support and encouragements whose love, affection and sacrifices has always stood by me and enabled me to this arduous destiny cheerfully.

Words are insufficient to express my gratitude to Dr. Samanpreet Kaur for her guidance during research.

I wish to extend my gratitude for all those persons, my memory had failed to recall, who rendered their support and services in various capacities throughout the tenure of this study. Above all, my gratitude to almighty for bestowing upon me his blessings throughout my studies.

Place:

Date: **(Palwinder Singh)**

Title of the thesis	:	Evaluation of abandoned wells for groundwater recharge
Name of student and Admission No.	: :	Palwinder Singh L-2K13/14-AE-191-M
Major subject	:	Soil and Water Engineering
Minor subject	:	Soil Science
Name of Major Advisor & Designation	:	Dr. Rajan Aggarwal Senior Research Engineer-Cum-Head
Degree to be awarded	:	M. Tech.
Year of award of Degree	:	2017
Total Pages in Thesis	:	36 + VITA
Name of University	:	Punjab Agricultural University, Ludhiana-141 004, Punjab, India

ABSTRACT

The Punjab State is facing continuous problem of declining groundwater table for last 2-3 decades. Wells which were used for withdrawal of water earlier have dried up and become abandoned. During rainy season and winter season irrigation water requirement through canal water reduces sharply. So, farmer can use surplus canal water for recharging groundwater. In the present study recharge rate and its impact under different conditions were studied for recharging groundwater through abandoned well. The recharge rate through abandoned well varies from 0.2 l/s to 7.67 l/s for different heads. The recharging of surplus canal water will improve overall quality of groundwater. Salinity and sodicity of groundwater decrease due to recharging of surplus canal water. Recharging abandoned well with gravel pack will improved overall capacity and life of abandoned well. There was negligible effect on rise in water table as limited volume of water for limited time was recharged.

Keywords: Abandoned well, Surplus canal water, Groundwater recharge

Signature of Major Advisor **Signature of Student**

ਖੋਜ ਗ੍ਰੰਥ ਦਾ ਸਿਰਲੇਖ	:	ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੀ ਰਿਚਾਰਜਿੰਗ ਲਈ ਬੇਕਾਰ ਹੋ ਚੁੱਕੇ ਖੂਹਾਂ ਦਾ ਮੁਲਾਂਕਣ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਦਾਖਲਾ ਨੰਬਰ	:	ਪਲਵਿੰਦਰ ਸਿੰਘ (ਐਲ-2013/14-ਏਈ-191-ਐਮ)
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ	:	ਭੂਮੀ ਅਤੇ ਜਲ ਇੰਜੀਨਿਅਰਿੰਗ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ	:	ਭੂਮੀ ਵਿਗਿਆਨ
ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ	:	ਡਾ. ਰਾਜਨ ਅਗਰਵਾਲ ਸੀਨੀਅਰ ਰਿਸਰਚ ਇੰਜੀਨੀਅਰ-ਕਮ-ਹੈੱਡ
ਡਿਗਰੀ	:	ਐਮ.ਟੈੱਕ
ਡਿਗਰੀ ਨਾਲ ਸਨਮਾਨਿਤ ਕਰਨ ਦਾ ਸਾਲ	:	2017
ਖੋਜ ਪੱਤਰ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ	:	36 + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ - 141 004, ਪੰਜਾਬ, ਭਾਰਤ

ਸਾਰ-ਅੰਸ਼

ਪਿਛਲੇ 2-3 ਦਹਾਕਿਆਂ ਤੋਂ ਪੰਜਾਬ ਨੂੰ ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੇ ਲਗਾਤਾਰ ਘੱਟ ਰਹੇ ਪੱਧਰ ਦੀ ਸਮੱਸਿਆ ਦਾ ਸਾਹਮਣਾ ਕਰਨਾ ਪੈ ਰਿਹਾ ਹੈ। ਪੁਰਾਣੇ ਸਮੇਂ ਵਿੱਚ ਪਾਣੀ ਲੈਣ ਲਈ ਜਿਨ੍ਹਾਂ ਖੂਹਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਜਾਂਦੀ ਸੀ ਉਹ ਹੁਣ ਸੁੱਕ ਚੁੱਕੇ ਹਨ ਅਤੇ ਬੇਕਾਰ ਹੋ ਚੁੱਕੇ ਹਨ। ਵਰਖਾ ਅਤੇ ਸਰਦੀਆਂ ਦੀ ਰੁੱਤੇ ਸਿੰਚਾਈ ਲਈ ਨਹਿਰੀ ਪਾਣੀ ਦੀ ਬਹੁਤ ਘੱਟ ਲੋੜ ਪੈਂਦੀ ਹੈ। ਇਸ ਲਈ ਕਿਸਾਨ ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੇ ਪੱਧਰ ਨੂੰ ਉੱਚਾ ਚੁੱਕਣ ਲਈ ਨਹਿਰੀ ਪਾਣੀ ਦੀ ਵਰਤੋਂ ਕਰ ਸਕਦੇ ਹਨ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ ਸੁੱਕ ਚੁੱਕੇ ਖੂਹਾਂ ਦੀ ਰਿਚਾਰਜਿੰਗ ਲਈ, ਵੱਖੋ-ਵੱਖਰੇ ਹਾਲਾਤਾਂ ਅਧੀਨ ਰਿਚਾਰਜ ਦੀ ਦਰ ਅਤੇ ਪ੍ਰਭਾਵ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਵੱਖੋ-ਵੱਖਰੇ ਮਾਪਦੰਡਾਂ ਲਈ ਬੇਕਾਰ ਹੋ ਚੁੱਕੇ ਖੂਹਾਂ ਦੁਆਰਾ ਰਿਚਾਰਜ ਦੀ ਦਰ 0.21 ਲੀਟਰ/ਸਕਿੰਟ ਤੋਂ 7.67 ਲੀਟਰ/ਸਕਿੰਟ ਤੱਕ ਦਰਜ ਕੀਤੀ ਗਈ। ਵਾਧੂ ਨਹਿਰੀ ਪਾਣੀ ਦੁਆਰਾ ਰਿਚਾਰਜਿੰਗ ਕਰਨ ਨਾਲ ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੀ ਗੁਣਵੱਤਾ ਵਿੱਚ ਸੁਧਾਰ ਹੋਵੇਗਾ। ਵਾਧੂ ਨਹਿਰੀ ਪਾਣੀ ਦੁਆਰਾ ਰਿਚਾਰਜਿੰਗ ਕਰਨ ਨਾਲ ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੇ ਖਾਰੇਪਣ ਵਿੱਚ ਕਮੀ ਆਉਂਦੀ ਹੈ। ਥੋੜ੍ਹੇ ਸਮੇਂ ਲਈ ਥੋੜ੍ਹੇ ਪਾਣੀ ਨਾਲ ਰਿਚਾਰਜਿੰਗ ਕਰਨ ਕਰਕੇ ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੇ ਪੱਧਰ ਉੱਪਰ ਨਾ-ਮਾਤਰ ਪ੍ਰਭਾਵ ਵੇਖਿਆ ਗਿਆ।

ਮੁੱਖ ਸ਼ਬਦ: ਬੇਕਾਰ ਹੋ ਚੁੱਕੇ ਖੂਹ, ਵਾਧੂ ਨਹਿਰੀ ਪਾਣੀ, ਜ਼ਮੀਨ ਹੇਠਲੇ ਪਾਣੀ ਦੀ ਰਿਚਾਰਜਿੰਗ

ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ | **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION AND SYMBOLS

cm	Centimeter
m	Meter
L	Liter
l/s	liter/second
l/min	liter/minute
ET	Evapotranspiration
K	Hydraulic conductivity
NTU	Nephelometric turbidity units
RSC	Residual sodium carbonate
PVC	Polyvinyl chloride

CHAPTER I

INTRODUCTION

Geographical area of Punjab is only 1.57 percent of total area of India, but it contributes more than 25 per cent food grains in the central pool. Cultivation is done in more than 83 per cent land of Punjab, whereas in India only 40.34 percent area is under cultivation (Gupta 2009). Irrigation water demand increased from last 3-4 decades due to increase of wheat and paddy cropping pattern in Punjab. The average annual rainfall is 650 mm and is ill distributed in time and space (Jain and Kumar 2007). As a result, the number of tube wells has increased from 1.92 lakh to 14.06 lakh for the period 1970 to 2015 (Anon 1970, 2015). The increased demand of water resources has created problem of water table decline in most parts of state. The rate of water table decline increased from 18 cm during 1982-87 to 42 cm during 1997-2002 (Hira *et al* 2004) and further to 75 cm during 2002-06 (Singh, 2006). Also, the area with water table depth > 10 m, has increased from 20 to 58 percent during 1998 to 2006 respectively (Kaur *et al* 2011), which indicates continuous overexploitation of groundwater resource of the state.

Groundwater resource estimation of Punjab state has been carried out as per Ground Water Resource Estimation Methodology (GWREC August 2014). The present condition of groundwater development in Punjab is very serious as more than 80 per cent of monitored wells are considered as overexploited (CGWB, 2012). Availability of groundwater of 21.44 billion m^3 annually is less as compared to annual groundwater extraction in Punjab which is estimated at 31.16 billion m^3. The major districts affected are Sangrur, Mansa, Moga, Ludhiana, Amritsar, Fatehgarh Sahib, Jalandhar, Kapurthala, Nawanshahr, and Patiala Districts. The situation in the state is so alarming that 110 blocks out of 138 blocks are categorised as overexploited, that is groundwater extraction in these blocks exceeds the natural replenishment of groundwater and 4 blocks are critical, 2 blocks are semi-critical and only 22 blocks are in safe category.

Therefore, considering the insidious and seriousness of the problem, it warrants to develop techniques to arrest this declining trend. The rate of declining water table can be arrested through artificial groundwater recharge subject to availability of good quality water and favourable geo-hydrological conditions (CGWB 1994). Based on declining rate of water level and its trend, about 26,650m^2 of the area has been demarcated for artificial recharge. The demarcated area for artificial recharge in Sangrur, Ludhiana, Moga, Amritsar, Kapurthala, northern parts of Ferozepur, Moga, Patiala, Jalandhar and some parts of Ropar and Nawanshahr districts extending in a north west to south east direction (Gupta 2009). Village ponds, an integral feature of most villages of Punjab, which have been neglected over the years, can be renovated by desilting, so as to increase their seepage rate and used for recharge purpose. Surface drain network was installed in early 1960 to reduced water logging and floods could now be utilized for artificial groundwater recharge by diverting surplus canal water into them. However, the surplus canal water must be controlled in such a manner that the releases match with the seepage loss in the drain section.

In Punjab, three fourth of the irrigated area is through tube wells and only one fourth area is canal irrigated. Canal water is supplied to farmers as per their warabandi schedule, mostly on weekly basis. Sometimes, canal water is available but not required in the field. In such cases the farmers usually diverts the available water toward the next field where ultimately it's accumulated at the tail end causing problem of stagnation. In recent years (2013-2014, 2014-2015) more rainfall occurred during winter season. Wheat is the major crop of Punjab it covers an area more than 3.5 million hectares in the state. It requires 4 to 6 irrigation. If rainfall occurs frequently, during rabi season wheat requires only 1 to 2 irrigations. Under such situations, the surplus canal water may be used for groundwater recharge. Further, in declining water table areas many wells which were dug to install centrifugal pumps have been abandoned as the water table declined and centrifugal pumps have been replaced by submersible pumps. These abandoned wells are available at the field level and their potential as recharge wells may be explored by diverting surplus canal water into them. This will help in utilizing the surplus canal water for recharge which will help in augmenting the depleted groundwater resource and help in arresting the decline in water table. Keeping the above in view, the study has been planned in the following objectives as listed below:

1.1 Objectives

1. To estimate the recharge rates from abandoned dug wells.
2. To study the impact of recharge on the water table depth.

CHAPTER II

REVIEW OF LITERATURE

Suter and Harmeson (1960) described various types of recharge pits and operating techniques developed by Illinois State Water Survey. These were built by local industries. Initial rates were reported as high as 14.9 feet per day, which is the height of column of water filtering into unit surface area during twenty-four hours. Average rate of recharge for this method have been estimated between 0.5 and 1.5 feet per day. Artificial recharge from pits, trenches, or a basin ordinarily is not considered feasible in situations where a thick layer of slowly permeable material exists near the surface. Results of a field investigation of recharge from an irrigation tail-water pit indicate that pit or trench recharge is feasible under this condition for a narrow pit or trench 525 feet long and 10 feet deep. This has the potential for recharging at a rate of 1 million gbd. The more highly conductive layer acts as a subsurface spreading basin which greatly enhances the opportunity for recharge.

Brown and Signor (1974) observed that artificial recharge was quite similar to liquid waste disposal through deep wells. The objective of artificial recharge is to store and retrieve of good quality water in waste disposal and to store permanently poor quality water. The unsaturated zone between the land surface and the water table is the largest potential reservoir for the storage of utilizable water. Brune (1970) estimated that 60-70 percent's of dewatered storage capacity of Texas underground reservoirs have been reused for water storage by artificial recharge. Bouwer (1989) observed that groundwater pumping must be managed so that it will not exceed the safe yield or the natural recharge rate of the aquifers. This may range from less than 1% of average precipitation in arid to semi-arid climates, to 20% of average precipitation in Mediterranean-type climates and 50% in cool and humid climates as in north-western Europe.

Sridharan *et al* (1990) numerically analysed the flow of water to a dug well in an unconfined aquifer by considering elastic storage release, well storage, anisotropy, gravity drainage, partial penetration, vertical flow and seepage surface at the well face. The water table in the aquifer and water level in the well was treated as unknown boundaries. The constant pumped discharge was maintained. Two-level iterative scheme was used to obtain the solution. The governing factors effects on the drawdown, development of seepage surface and contribution from aquifer flow to the total discharge were analysed. Analysis showed that the flow characteristics were most significantly affected by degree of anisotropy and partial penetration. The anisotropy effect on the development of seepage surface was much pronounced.

Khepar (2000) studied the groundwater recharge modelling for surplus canal water releases through surface drainage system. In many countries intensive agriculture has led to over-exploitation of groundwater resources which results in decline of water table. Artificial groundwater recharge prevents the declining of water table. The Indo-Gangetic plain of India is facing the problem of a decline of water table. The constructed network of surface drains to control water logging could be used for groundwater recharge with surplus canal water in the low irrigation requirement period. The results indicate that recharging the declining water table by surface drainage systems. Surface drain network was installed to reduce water-logging and floods could now be utilized for artificial groundwater recharge. The network of canal irrigation and surface drains were always cross to each other. Surplus canal water applied in the low crop water requirement period, provide a feasible source of water for recharge by using existing surface drainage system.

Bouwer (2002) observed that artificial groundwater recharge is obtained by putting surface water in basins, ditches and furrows from where it infiltrates into the soil and percolate to recharge aquifers. For short or long-term underground storage, artificial recharge is increasingly used. Where it has many advantages the water was stored in dry zone and reused. Artificial recharge needs permeable surface of soils. Trenches or shafts in the unsaturated zone can also be used for directly injection of water into aquifers through wells. Infiltration rates of the soil must be determined to design a system for artificial recharge of groundwater and the unsaturated zone between land surface and the aquifer must be checked for adequate permeability and absence of polluted areas. The aquifer should be sufficiently transmissive to avoid excessive build-up of groundwater mounds. Knowledge of these conditions requires field investigations and if no fatal flaws are detected, test basins to predict system performance. Water quality issues must be evaluated and especially with respect to formation of clogging layers on basin bottoms or other infiltration surfaces, and to geochemical reactions in the aquifer. Clogging layers are managed by de-silting or other pre-treatment of the water and by remedial technique in the infiltration system. Such as drying, scraping, disking, ripping or other tillage. Recharge wells should be pumped periodically to backwash clogging layers.

Kaledhonkar *et al* (2003) observed that artificial recharge of groundwater by tube wells. Artificial recharge of depleting groundwater is carried out by installing two-recharge tube wells in the bed of old Sirsa branch canal. Selection of depth of recharge and location of tube wells was based on the resistivity survey results. To avoid the entry of sediments and suspended solids particles in recharging water, desilting units were installed. The performance of recharge tube wells were observed well without any decrease in recharge rate in entire experimental period covering two monsoon seasons. An average recharge rate of 10.5 l/s due to individual recharge tube well was observed, which was reasonably good.

Guo, James (2003) studied the design of storm water storage basin for both subsurface seepage flow and surface infiltrating flow. This paper observed that the basin storage volume shall not exceed the storage capacity of soil pores. Whereas, for a long-period groundwater recharging basin and the subsurface geometry at the basin location should be capable to conduct the surface infiltrating water. For preventing a delayed drainage operation, an infiltrating basin should be planned with consideration of the storage capacity of soil pore before the soil media is saturated and the soil transportation capacity after saturation. In this situation, the capacity flow model is used to calculate volume of the soil pore storage below the basin and to estimate the transportation capability by the saturated soil media between the basin and the adjoining water table. The capacity flow model for infiltrating water flow gives a quantifiable method to determine the soil condition and to compare various options at the basin location. This study involves the idea of a fixed hydraulic conductivity to the capacity flow model by which the motion of the wetting front can be calculated and the saturated soil volume below the basin can be estimated.

Goyal (2003) observed the efficiency of an irrigation engineer can be well judged from the canal water available at tail ends of the canals under his control. But often he finds it difficult to maintain authorised share of water at tails. In India position is particularly precarious during rice sowing period, which is monsoon season, i.e. rainy season in India at that time. It is the peak demand period for canal water. A deficit monsoon coupled with water theft makes it very difficult for authorised share to reach at tail ends. On the other hand, a good rain can cause tails to get flooded. It causes great loss to tail end users. This problem can be solved to some extent with the help of bore wells or dug wells, dug along the canal, more of them in the last one third of the length of the canal. These dug wells will act as rechargers of ground water during the period when there is excess of supply of water in the canals by diverting excess water to these bore wells and will act as boosters during short supply by drawing this water through tube wells and mixing it with canal water. Though conjunctive use of tube wells along with canal water is being practiced since long, this technique of first recharging aquifers with surplus canal water and then withdrawing this recharged ground water through tube wells during peak demand period, is particularly useful where ground water is otherwise brackish and is unfit for use.

Lluria (2009) studied the artificial groundwater recharge techniques currently completely involved in the water sources planning in the Arizona State. The study of water quality changes after passing through the soil to be cleaned, for which experiments were conducted by the University of Arizona. After that, a moist period suffered in leading to storing excess surface water through artificial recharging dried aquifers. The laws established in 1980 and 1986 the legal framework for all manage aquifer recharge aspects. So, the most developed artificial recharge projects in Arizona were Granite Reef Underground Storage Project, Central Arizona Project and Salt River Projects. They have contributed to a very important development of these methods and have provided better results.

Aggarwal *et al* (2009) analysed the declining water table problem and its possible factors responsible and also suggested suitable strategies for arresting declining water table for sustainable agriculture in Punjab. The strategies include change of cropping pattern, precision irrigation, delay in paddy transplantation for more utilization of monsoons period and rain water harvesting for artificial recharging of groundwater.

Bhattacharya (2010) observed that artificial ground water recharge is a procedure by which the groundwater aquifer is increasing at a rate exceeding the increase rate under natural conditions of replenishment. In some regions of India, due to over use of groundwater, decrease in water tables resulting in scarcity of water and interference of saline water in coastal areas have been predicted. The choice of a specific method is governed by local topographical, geological and soil conditions and also quality and quantity of water available for recharge and the technological-economical suitability and social acceptability of such projects. The artificial recharge using injection wells were studied in the Ghaggar River basin by canal water as the primary surface-water source for groundwater recharging. The injection rate of recharge was initially 43.8 litres per second at an injection pressure of 1 atm. The pressure was raised to 2 atm after 5 hours and the recharge rate gradually decreased to 3.5 l/s after some days.

Patel *et al* (2010) observed that over-use of regional groundwater sources can be avoided by leading groundwater mounding through artificial recharge using rain water stored in specially designed basins. In order to maintain the local water balance and to sustainable use of water supply information of water table fluctuation correspond to the proposed recharge project is essential. In this study application of the location criteria for recharge bore well is mentioned. Also focused on collection of surrounding location geotechnical input, geometrical parameters, topography of the location and evaluation of aquifer and modelling of ground water. Mathematical modelling of ground water flow related to unconfined aquifer with a change in saturated thickness with variation in piezometric level, permeability, radius of influences and presence of recharge by rainfall is mentioned here. The significant relationship can be calculated by using quadratic mathematical expressions, drawdown and detention time of water storage can also be determined. The technique is applied to an unconfined aquifer with horizontal impervious base receiving vertical recharge using rain water stored in specially designed basin. Authors have set up precast octagonal recharge well system at proposed site and suggested design parameters for roof top rain water recharge system. Recharging capacity of well can be calculated by field test and confirmed with analytical solution.

Sayana *et al* (2010) studied the outcome of groundwater after artificial recharge of rainwater through roof top in the St Peter’s Engineering College campus, Avadi, India and indicated that rainwater harvesting and recharge studies form an important part in groundwater recharge and management in intensely urbanized cities/townships.

Magnus and Adindu Ruth (2011) observed the groundwater recharge by process infiltration. The high pumping of groundwater leads to depletion of the groundwater table. Rainfall and excess canal water is the main natural source of groundwater recharge. Study of Umudike, South-eastern Nigeria just similar to other places, the rate of natural recharge is lower than discharge rate. This is due to increasing economic and agricultural activities and also urbanization. Over use of groundwater is a critical condition to the water table and quality and leads to hydrological imbalance. This imbalance includes degradation in hydrological and hydro-chemical attributes of the aquifer. Artificial recharge of water table aquifers becomes important to improve the hydrodynamic situation of groundwater. A drop in piezometric level can be controlled by artificial recharge of groundwater by infiltration procedure using water from dams, lakes, rivers, and runoff and sewage wastes. Results of water table survey conducted at Umudike show that it peaks at 85 m (above sea level) before recharge and 95 m after recharge. The recharge of groundwater mainly occurred due to rainfall and river water.

Ravichandran *et al* (2011) observed that groundwater has a significant role in the country in improving agricultural production, drinking water and facilitating industrial development. In India groundwater provide nearly 55 percent of irrigation water, 85 percent of rural water and 50 percent urban water and industrial water needs. In order to improve the ground water condition it is important to artificially recharge the depleted groundwater aquifers. The abandoned dug wells can be used as recharging structure for groundwater reservoir. Excess flow of storm water, tank water, canal water etc. can be diverted toward the dug well to recharge the dried aquifer. Injections well are also used for augmenting the groundwater storage of a confined aquifer by recharging the surface water under pressure. Dual-purpose injection wells cum pumping wells are more efficient according to study.

Santosh *et al* (2011) conducted a study in the Gamanagatti (1002 ha) micro watershed which is located at a distance of 12 Km from Hubli city of Karnataka state. The individual farmer adopted different package of conservation practice on their own depending upon the requirement and availability of resources. Five farms were selected in the Gamanagatti micro watershed based on prospectus of ground water resources, of imposition of all extent of possible combination farm level water conservation methods and readiness to adopt improved conservation practices and experiment were carried out. The evaluation of water conservation methods was carried out in terms of physical, social and economic aspects.Watershed management of watershed, Dharwad district in Karnataka state and revealed that during recent times, farmers in many parts of state are facing the threat of over use of groundwater which clearly depicts the gap between groundwater recharge and ground water usage or pumping rates. The commonly adopted dimensions of farm ponds were 12m×12m×4m with a maximum storage capacity of 400 m^3. Recharge pits were constructed with the dimensions of 10 m×10 m×4m depth to collect field runoff for recharging bore wells.

Hassan *et al* (2013) observed that less supply of fresh water and its high shortage has led to the greater effect on water resources management. Recharge is an important parameter for understanding, modelling and protecting groundwater systems from overexploitation and contamination. Adopting the concept of sustainability and conservation of water resources using artificial recharge method can help mitigate with the global water scarcity. This study indicates the effect of hydraulic and geotechnical parameters on the different groundwater recharge methods with respect to three techniques mostly utilized in KSA (surface spreading, injection wells into vadose zone and direct injection wells into the aquifer. In every technique, recharge capacity is analysed at different geotechnical parameters. Also, the effect of geotechnical parameters on moist front and infiltration rate of surface distribution methods are analysed. Moreover, the effect of deposition of suspended fines i.e. clogging on the recharge rate is observed.

Hashemi *et al* (2013**)** estimated the change in groundwater recharge from an introduced artificial recharge system is critical in order to estimate future water supply. This paper presents an inverse modelling basis to calculate the recharge contribution from both an ephemeral river channel and an introduced artificial recharge system based on floodwater distribution in arid Iran. The study used the MODFLOW-2000 to calculate recharge for both steady and unsteady-state situations. The model was calibrated and validated based on the noted hydraulic head in observation wells and model precision, uncertainty, and model sensitivity were observed in all modelling steps. Outcome indicates that in a normal year without extreme events, the floodwater distribution system is the main supply to recharge with 80% and the ephemeral river channel with 20% of total recharge in the studied region. Uncertainty analysis indicates that the river channel recharge estimation represents relatively more uncertainty in comparison to the artificial recharge zones. The model is also less sensitive to the river channel. The outcome indicate that by expanding the artificial recharge system, the recharge volume can be increased even for small flood events, while the recharge through the river channel rise only for major flood events.

Muthukrishnam *et al* (2013) observed the importance of water in all sector requirements and needs of the population is growing. The topic of the present study is a representative case of over use of groundwater sources, leading to the continuous exhaustion of the grained as well as the ground water aquifers. The utilization of the increasingly and internationally popular method of artificial recharge on the groundwater aquifer was chosen to be the most useful for the restoration of budget of the hydro-geological systems. Use of finest technology and calculation of all the parameters involved, which are important, have been considered. To identify the suitable locations for an artificial recharge areas an integrated basis of remote sensing and GIS approach techniques were employed. The study focuses on development of remote sensing and GIS based analysis and methodology in groundwater recharge studies in watershed. In order to showing the Role of remote sensing and GIS based methodology, the basin of Shanmuganadi sub watershed in Cauvery river basin Tiruchirappalli district state of Tamil Nadu (India) has been taken for observation.

Narula (2014) observed the groundwater draft exceeding the groundwater recharge resulting in over use of groundwater aquifers. This has resulted in continuous decline in water levels and reduction in the yield of the tube wells. Due to poor rainfall probability and recurring drought situation, the area could never restore the scarcity of water extracted from groundwater sources. The artificial recharge to groundwater can only sustain the water levels or can control the rapid depletion of groundwater rate. The part of Patantaluka in Gujarat, India is selected for the construction of artificial recharge structures near the large storage village ponds. It was suggested to construct artificial recharge structures in seven villages of Patantaluka near these village ponds. The recharge capacity is estimated taking 40 rainy days taking average rainfall as 77.0 cm. If the recharge shaft is linked to the ponds at a level, it is able to utilize the storage of ponds and recharge capacity can then be estimated for a period of 180 days (pre-monsoon and post-monsoon period). Therefore estimating the runoff potential of seven recharge constructions and assessing the catchment of the area, the design is considered feasible for recharge in seven villages of Patantaluka.

Narjary *et al* (2014) studied that effect of rainfall variability on groundwater resources and opportunities of artificial recharge structure to reduce its exploitation in fresh groundwater zones of Haryana Climate change likely to impact rainfall patterns leading to higher uncertainty and difficulties in management of both water scarcity and flood events. Analysis of long-term rainfall data (1972–2010) indicated that Karnal receives a mean annual rainfall of 75.76 cm with a high degree of variation (Coefficient of variation = 34.3 percent). Classification of seasonal rainfall based on long-period average (LPA) and its Coefficient of variation indicates that during the recent years (2001-2010). Karnal received deficit rainfall in 6 years (18-57% lower than LPA), normal rainfall in 2 years and excess rainfall (9-70%higher than LPA) also for 2 years. The rainfall and rainy days during the last decade (2000-2010) decreased by 13% and 20% respectively, over long term (1972-2010) averages. AGR through recharge wells installed by CSSRI at village Nabiabad in Karnal districts resulted in 232 cm and 316 cm rise in water table during 2009 and 2010 respectively. Installation of artificial groundwater recharge in lower elevation areas has proven more effective in increasing the water table and improves its quality. The groundwater decline can be deferred to some extent by increasing artificial recharge by excess rain water and surplus canal water through surface spreading technique and direct injection well recharging. Artificial groundwater, recharge by diverting the excess flow of rain water and surplus canal water under gravity through dug wells and tube wells. The flow of water downward infiltrate through subsurface dried zones, soil profiles work as recharging filter consisting of layers of coarse sand, sand, small gravel and boulders in a small brick masonry chamber.

Emily *et al* (2016) studied that drywells are freely suspended, excavated pits with perforated casings used to facilitate storm water infiltration and groundwater recharge in areas where drainage and diversion of storm flows is critical. Historically, drywells have predominantly been used as a form of storm water management in sites that collect high amount of rainfall, however the use of drywells is increasingly being assessed as a techniques to complement groundwater recharge, especially in areas facing severe drought. Studies have shown that drywells can be an effective means to increase recharge to aquifers. However, the capacity for groundwater contamination caused by polluted storm water runoff bypassing transport through surface soil and near surface sediment has prevented more widespread use of drywells as a recharge mechanism. A number of studies have indicated that groundwater and drinking water pollution from drywells can be prevented, if drywells are utilized in suitable sites and properly conditioned. The effectiveness of drywells for aquifer recharge relay on the hydro-geological setting and land use surrounding a site, as well as influent storm water amount and quality. These components may be specified for drywell location through geologic and hydrologic characterization and adequate monitoring of storm water and groundwater quality.

CHAPTER III

MATERIAL AND METHODS

This chapter includes the description of study area, criteria for selection and location of abandoned wells and methodology for estimating the quantity and quality of groundwater and recharging water. Accordingly, the chapter is divided into the following sections:

3.1 Description of the study area

3.2 Selection and location of abandoned well

3.3 Improvements/ modification of abandoned dug wells

3.4 Installation of observation wells

3.5 Recharging of abandoned wells

3.6 Collection and testing of groundwater, canal water and soil samples

3.7 Hydraulic conductivity

3.8 Statistical analysis

3.1 Description of the Study Area

3.1.1 Location

The state of Punjab is located in the northwest of India. The location map of the study area Punjab Agricultural University (PAU) Ludhiana is shown in Fig. 3.1. Ludhiana is located at 30.9°N 75.85°E. It has an average elevation of 244 metres (798 ft).

Fig. 3.1 Location Map of Punjab

3.1.2 Climate

The study area is characterized by sub-tropical and semi-arid type of climate with hot and dry summer from April to June followed by hot and humid period during July to September and cold winters from November to January. The mean maximum and minimum temperatures show considerable fluctuations during different parts of the year. Summer temperature averages around 38°C and touches 45°C with dry summer spells. Winter experiences frequent frosty spells especially in December and January and minimum temperature dips up to 0.5°C. The average annual rainfall of Ludhiana is 733 mm (Kingra *et al* 1996) the major portion of which (75%) is received during July to September. For the present study the field experiment was conducted from Dec, 2013 to July, 2016.

3.2 Selection and Location of Abandoned Wells

Four abandoned wells at different locations in PAU were selected and location map is shown in Fig. 3.2. The surplus canal water was used for recharging groundwater at three different locations in the farm of Soil Science Department and one location at the farm of Agronomy Department in Punjab Agricultural University. The following criterion was kept in mind for selection of abandoned wells for artificial groundwater recharge.

Fig. 3.2 Google earth image of study area

1. Source of recharge water: The abandoned wells were selected so that the availability of canal water was at minimum distance from wells.
2. Chemical, physical and biological characteristics of recharging water
3. Availability of an aquifer suitable for recharge
4. Chemical characteristics of the native ground water
5. Water level differences between the aquifer and the recharging point
6. Topography
7. Adequate sunlight is available for proper visibility

3.3 Improvements and Modification of Abandoned Dug Wells

Initially, all the selected four wells were filled with agriculture and other waste material (Fig. 3.3 and Fig. 3.4).

Fig. 3.3 View of uncleaned abandoned well at site 1

Fig. 3.4 View of uncleaned abandoned well at site 2

The abandoned wells were cleaned to remove the foreign/extra material from the well. The depth of these four wells were about 6.41 m to 8.31 m. These abandoned wells were also at higher elevation, so the filter pits were dug before the well so that most of silt coming along the surplus canal water settles inside the filter pits and overflow from the pit is diverted into the well. The ground surface surrounding the well was made free from hindrances easy to facilitate the recording of observations. The site 1 was at the research farm of Soil Science department and the abandoned well was 1.88 m diameter and 8.31 m depth (Fig. 3.5). The lined water channel to carry canal water was at a distance 3 m from the abandoned well and flow was diverted from canal water channel to the dug well by gravity. The abandoned well was connected to dug well through PVC pipes of 5” diameter. There was bore well available in the well covered with the reflux valve. Water table depth was 24.70 m from the ground surface. At the top, the abandoned well was covered by iron grills for safety purpose. The observation well was installed at 6 m distance from the abandoned well to monitor the groundwater depth as well as quality.

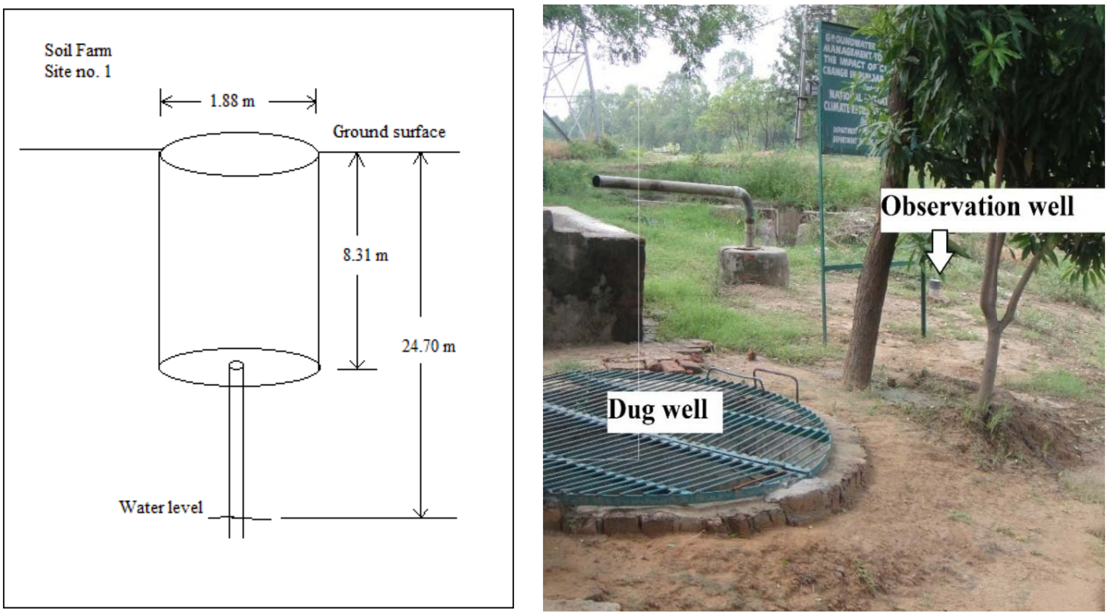

Fig. 3.5 View of abandoned well at site 1 and its dimensions

At site 2 and site 3 which were also in farm of Soil Science department, the abandoned well was at a distance of 8 m and 6 m from canal water channel. The dimensions of the abandoned well are shown in Fig. 3.6 and Fig. 3.7 respectively. The water table depth in these wells was 25.31 m at site 2 and 24.27 m at site 3 from the ground surface. The pre-existing bore wells in abandoned wells were covered with reflux valve to prevent the direct injecting the recharging water to well. The abandoned wells were connected to filter pits with PVC pipes, the excess flow of canal water from these filter pits were diverted to the recharging well. Obsevation wells were installed near to the recharging structure at distance 2.4 m and 2.7 m to monitor groundwater depth as well as quality

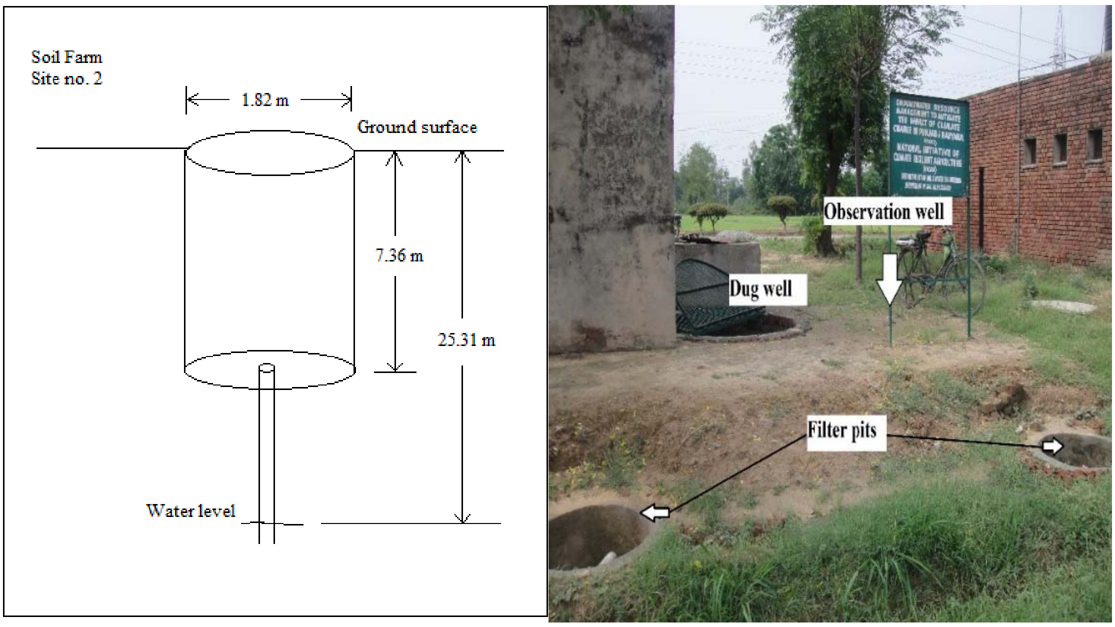

Fig. 3.6 View of abandoned well at site 2 and its dimensions

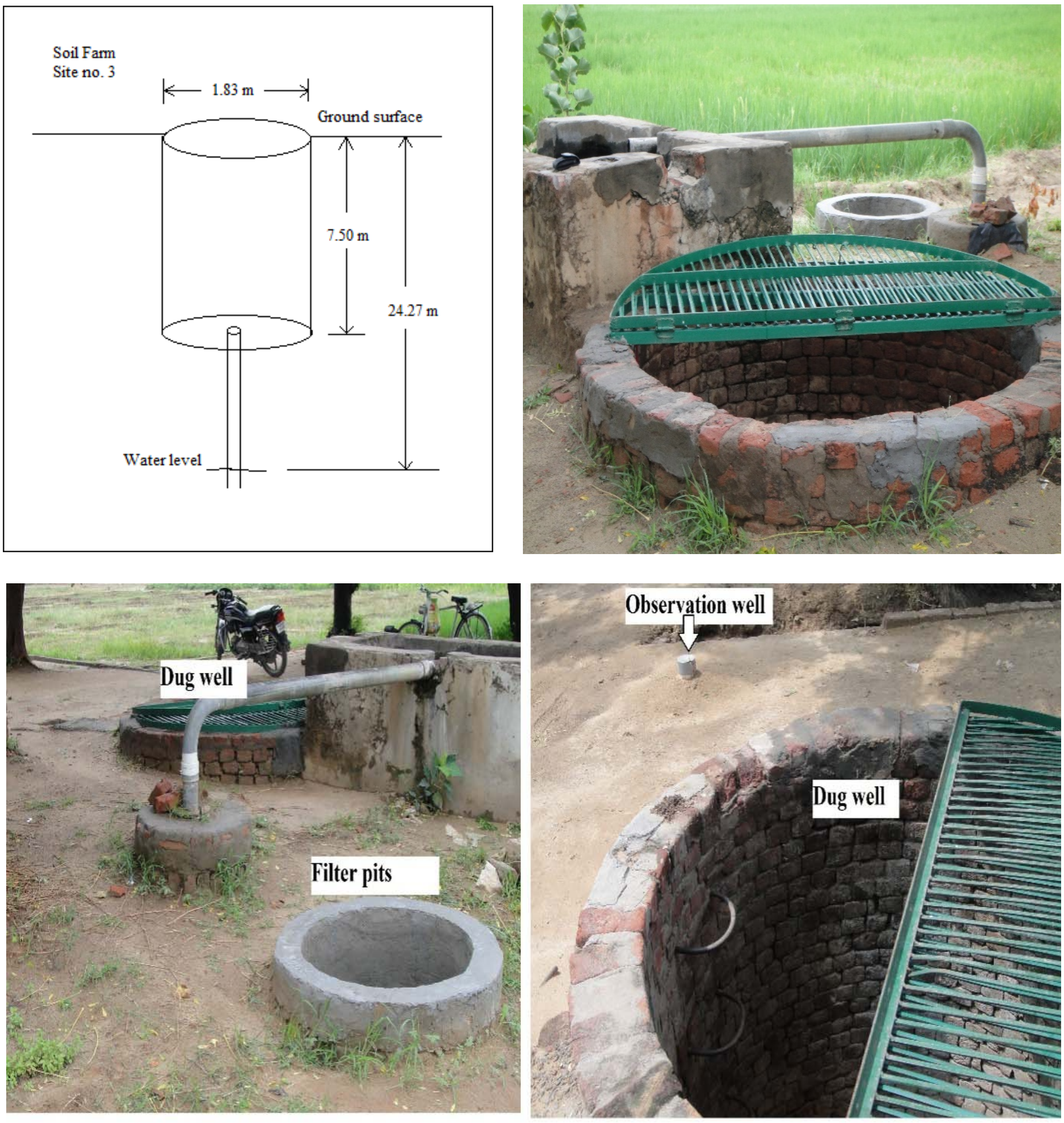

Fig. 3.7 View of abandoned well at site 3 and its dimensions

At site 4, in farm of Agronomy department, the selected abandoned well was at a distance 6m from canal water channel. The dimensions of the abandoned well are shown in Fig. 3.8. The water table depth in well is 23.4 m from the ground surface. The observation well was also installed at distance 4.98 m to monitor groundwater depth as well as quality.

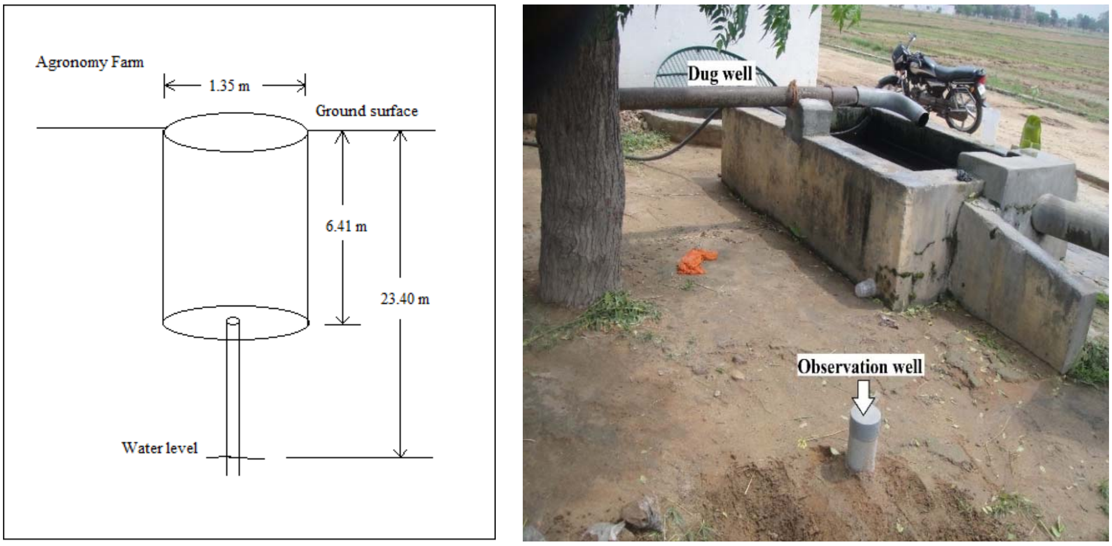

Fig. 3.8 View of abandoned well at site 4 and its dimensions

3.4 Installation of Observation Wells

Observation wells were installed at a distance of 2.4 m to 6 m at different sites near the abandoned wells to observe the recharging effects on quality and quantity of groundwater. Well log for different sites was prepared by taking sample during the installation of observation wells (Fig. 3.9). The measuring depth of groundwater level and groundwater samples was taken before and after the recharging. These observation wells were developed after every 6 month by submersible pump for protecting the blockage of well strainers (Fig. 3.10).

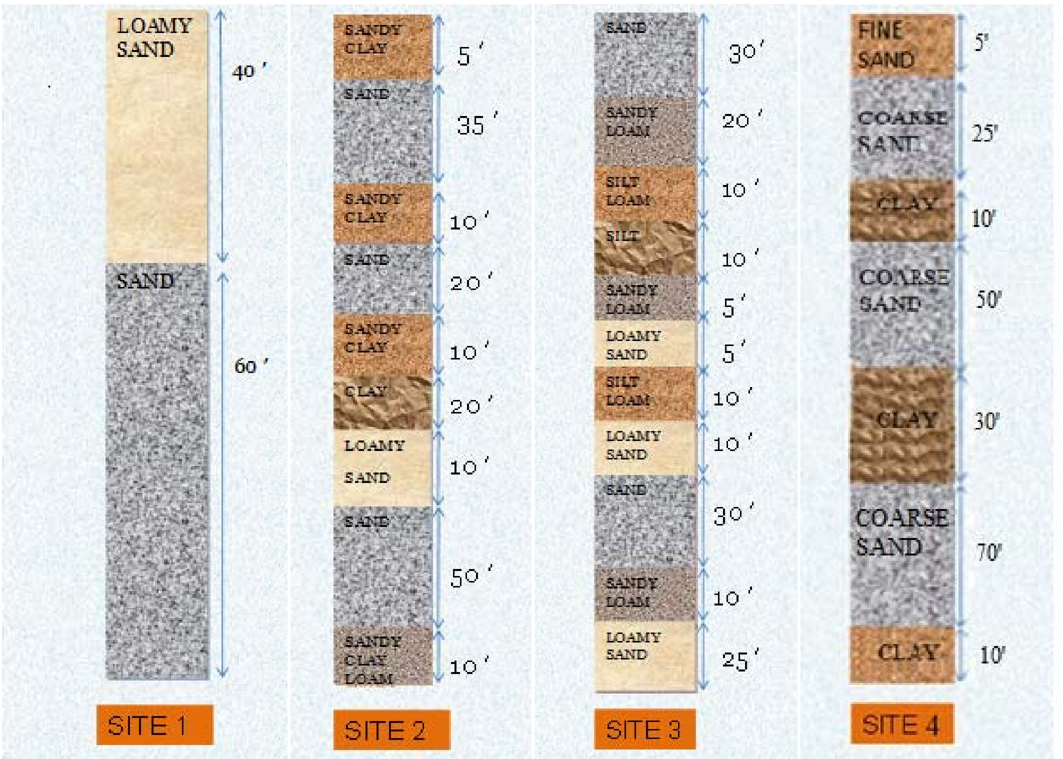

Fig. 3.9 Geological strata at all the four sites

Fig. 3.10 Development of observation well

3.5 Recharging of Abandoned Wells

After cleaning the abandoned wells, surplus canal water was directed toward the abandoned well and recharge rate was observed at different time intervals. Recharging rate from the wells were measured with and without placement of gravel pack layer. The gravel pack with a layer thickness of 0.65 m (broken bricks aggregates size 2-4 cm) was placed at the bottom of the four abandoned wells to increase the recharging life and to absorb the silt and clay particles of recharged water. Each experiment was replicated 15 times and the difference in recharging time for the same volume of water was noted.

3.6 Collection and Testing of Groundwater, Canal Water and Soil Samples

Soil samples were taken from bottom surface of wells at all the four sites before the start of experiment. A 6" layer from bottom surface was scrapped of well and soil samples were collected for estimating soil texture and NPK content from wells. The soil samples were also collected after recharging of water from the wells. The canal water and groundwater samples were also collected for testing the quality of water. The groundwater samples were taken from observation wells. The collected water samples were tested for pH, EC, RSC and chlorine content. The turbidity of canal water was also measured throughout the recharging periods.

3.7 Hydraulic Conductivity

Hydraulic conductivity is the rate at which volume of water is moving through a given area of aquifer when subject to a hydraulic gradient. Hydraulic conductivity is measured in volume per unit time per unit area (m/day). The rate of recharge from the well depends to a great extent on the soil's saturated hydraulic conductivity (K). Inversed auger-hole method was used for measuring of K value during recharge period (Fig. 3.11).

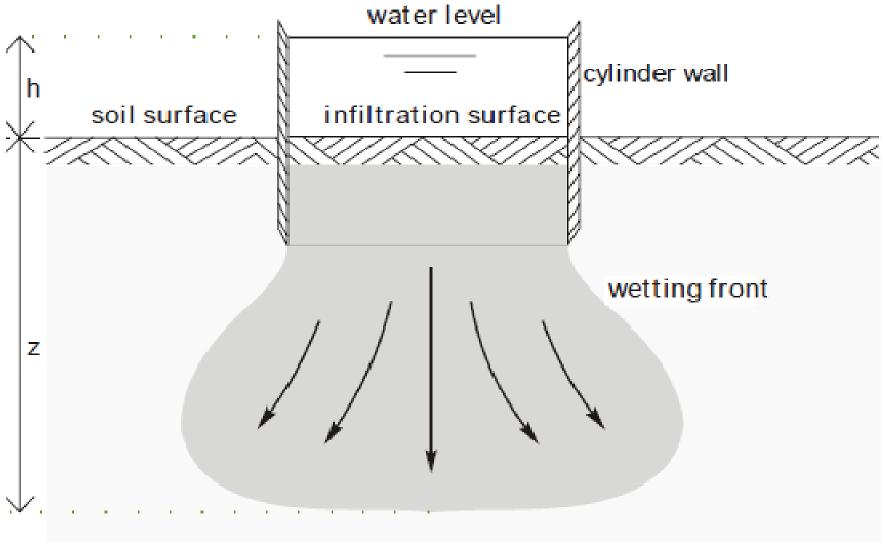

Fig. 3.11 Infiltration process beneath a cylinder infiltrometer

$$K = 1.15\, r \; \frac{\log (h_0+½r) - \log (h_t+½r)}{t - t_0}$$

where,

K = hydraulic conductivity of well

r = radius of recharge surface (cm)

t = time since the start of measuring (s)

h_t= the height of the water column in the hole at time t (cm)

h_0 = h_t at time t = 0

3.8 Statistical Analysis

The data collected on various aspects of the investigations was statistically analysed as prescribed by Cochran and Cox (1967) and adapted by Cheema and Singh (1991) in statistical package CPCS-1. The comparisons were made at 5 % level of significance. The experiment-wise split up of degree of freedom in the analysis of variance was followed in Table (3.1).

Number of treatments: 4×5 = 20

Number of replications: 5

Environment: 1

Table 3.1 Analysis of variance (ANOVA)

Source of Variance	Degree of Freedom
Treatments Error	3 16
Total	**19**

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, results obtained through the experiments conducted on artificial recharge of groundwater have been analyzed and discussed.

4.1 Soil Sample Analysis

Analysis of soil texture and observed change in percentage of sand, silt and clay throughout the study period with and without gravel pack is given in Table 4.1. A persual of the table reveals that there was change in percentage of sand, silt and clay with and without use of gravel pack. But the increase of clay and sand was much more without gravel pack in comparison to when water was recharged with gravel pack and decrease in sand percentage due to absorbtion of silt and clay by gravel pack.

Table 4.1 Per cent of sand, silt and clay and its variations of abandoned wells located at different sites

Site No.	Sample		Sand %		Clay %		Silt %		Texture
1	Before recharging		81.6	-	11.8	-	6.6	-	Loamy sand
	After recharging	Without gravel pack	77.7	-3.9	14.6	2.8	7.7	1.1	Loamy sand
		With gravel pack	76.5	-1.2	15.2	0.6	8.3	0.6	Loamy sand
2	Before recharging		85.3	-	3.4	-	11.3	-	Sand
	After recharging	Without gravel pack	82.9	-2.4	4.0	0.6	13.1	1.8	Loamy sand
		With gravel pack	82.3	-0.6	4.2	0.2	13.5	0.4	Loamy sand
3	Before recharging		88.2	-	4.1	-	7.73	-	Sand
	After recharging	Without gravel pack	86.5	-1.7	5.6	1.5	7.9	0.2	Sand
		With gravel pack	84.9	-1.6	6.8	1.2	8.3	0.4	Loamy sand
4	Before recharging		84.9	-	3.6	-	11.5	-	Sand
	After recharging	Without gravel pack	75.5	-9.4	10.0	6.4	14.5	3	Loamy sand
		With gravel pack	74.2	-1.3	11.5	1.5	14.3	-0.2	Loamy sand

4.2 Water Table Depth

The observation wells installed near each of the structure were monitored regularly with respect to groundwater depth. At all the sites, water table declined sharply in the month of July due to ET losses and over pumping for paddy crop and then it starts rising till

December. It was also observed that rate of water table decline was greater than the rate of rise. Observation wells were installed in year 2013 at site 1, site 2 and site 3. But at site 4 observation well was installed in June, 2015 as shown in Fig. 4.1.

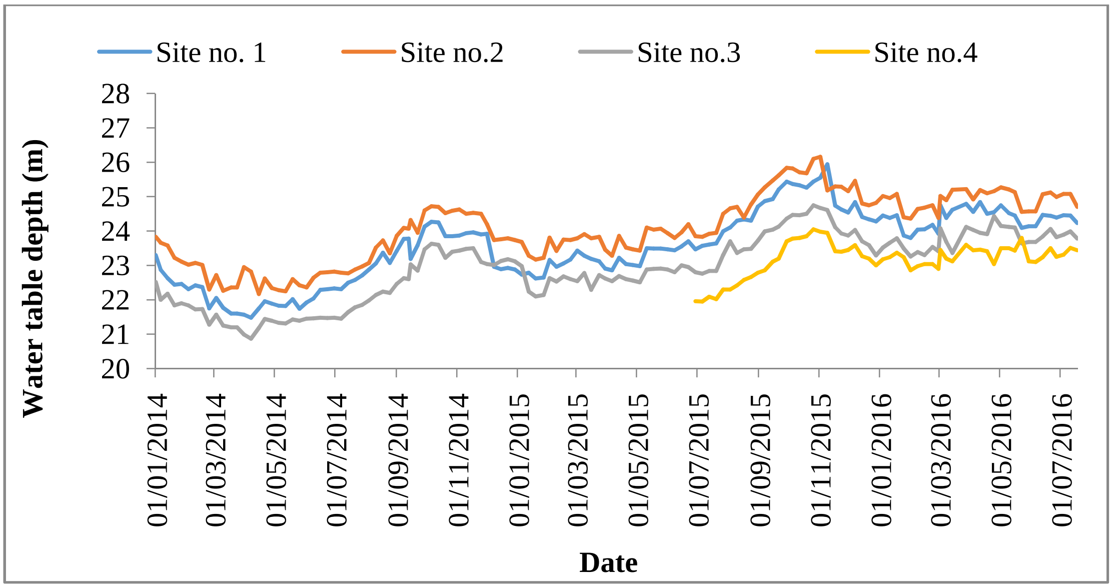

Fig. 4.1 Fluctuation at water table depth

4.3 Analysis of Water Samples

4.3.1 Turbidity

The turbidity of canal water was not giving any trend during the recharging periods. The maximum turbidity level of canal water was observed 95 NTU (Nephelometric Turbidity Units) during recharging. Turbidity level of recharging water varied in from 85 to 95 NTU (Nephelometric Turbidity Units) sediment load concentration.

4.3.2 Canal water quality

The quality of canal water varied significantly within the monsoon period. The pH, EC values and RSC values are shown in Fig. 4.2, Fig. 4.3 and Fig. 4.4 respectively. The parameters viz., pH and RSC were initially high in monsoon period and gradually decreased at the end of the October. However, EC values gradually decreased in month of June to August but slightly increased in September and October.

4.3.3 Recharge water quality

The quality of groundwater at all four sites in the abandoned well was monitored weekly to assess the impact of recharging on the groundwater. The samples were taken from the observation well installed near the abandoned well, in all the samples Organochlorines, Organophosphates, Synthetic pyrethroids and Herbicides were found to be below determination limit. The salinity remained within the permissible limit during pre-monsoon, post monsoon and during recharging period. However in monsoon season salinity was lowest at four sites and RSC values also reduced during the monsoon season (July to September).

The pH was within normal range throughout the recharging periods and water quality was improved (Fig. 4.5). At site 1 pH fluctuated more at initial recharging periods in comparison to other sites. EC values of four wells were showed little variance during recharging periods. These were under permissible limits (Fig. 4.6). RSC values of four observation wells were reduced during the monsoon period (Fig. 4.7).

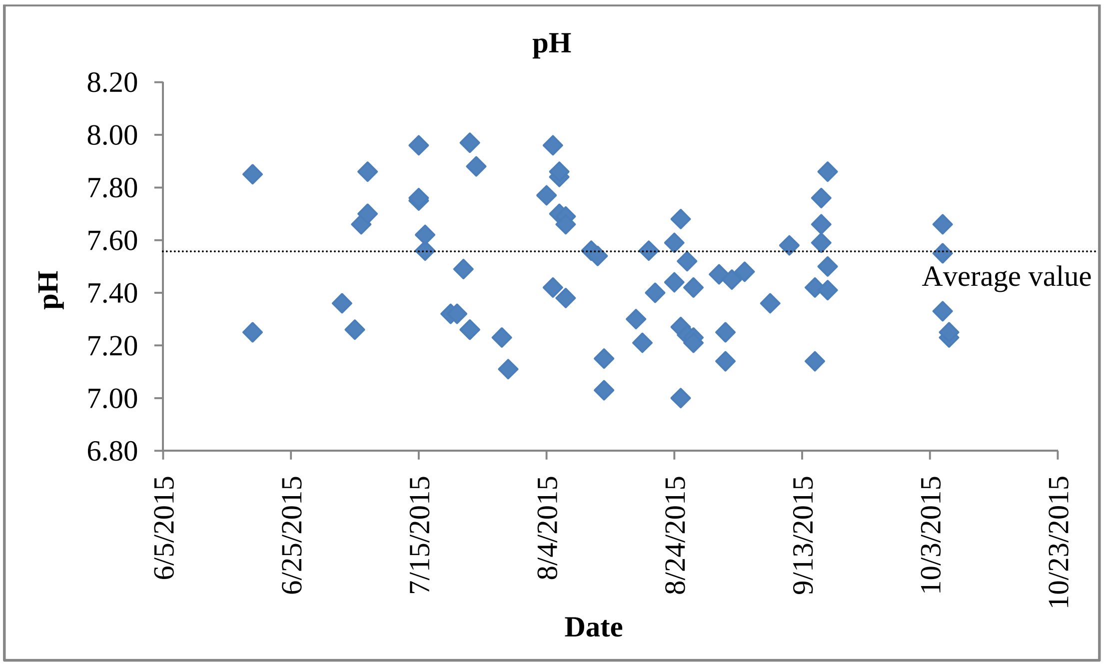

Fig. 4.2 pH values of canal water

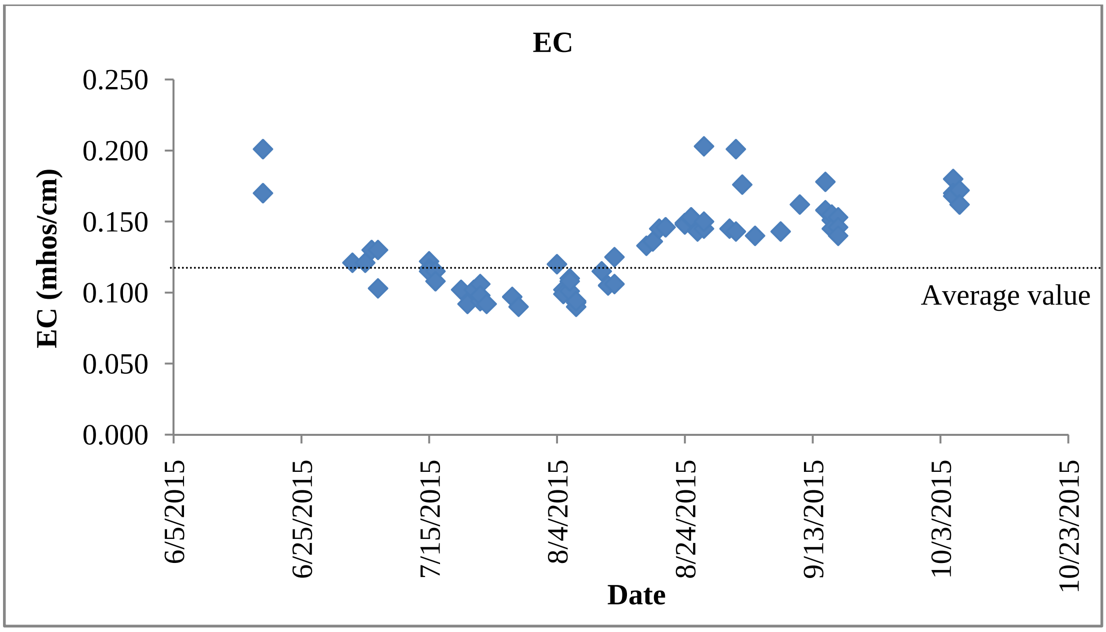

Fig. 4.3 Electrical conductivity (mhos/cm) values of canal water

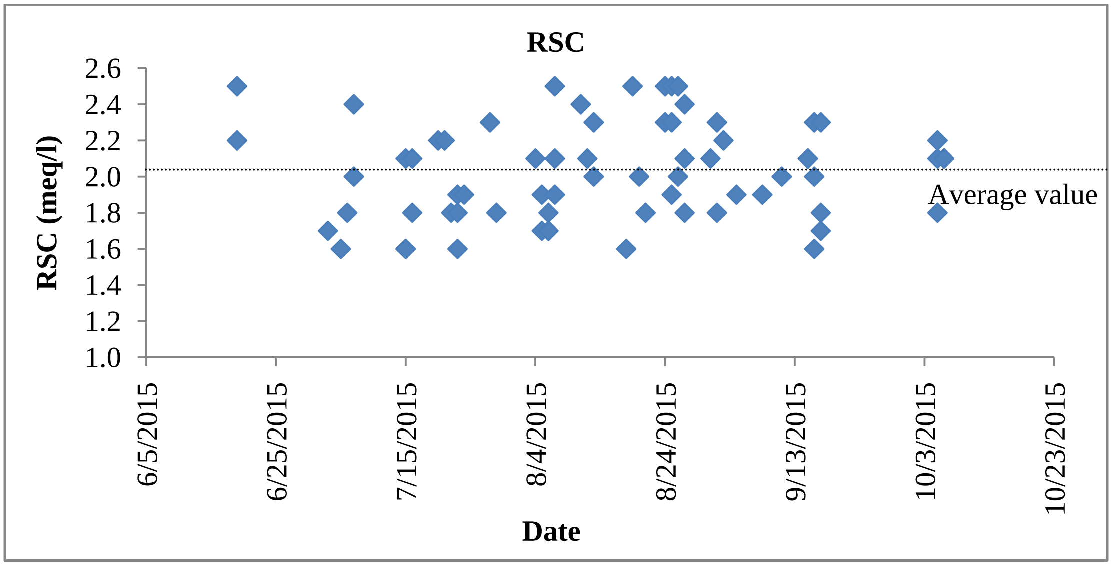

Fig. 4.4 RSC (meq/l) values of canal water

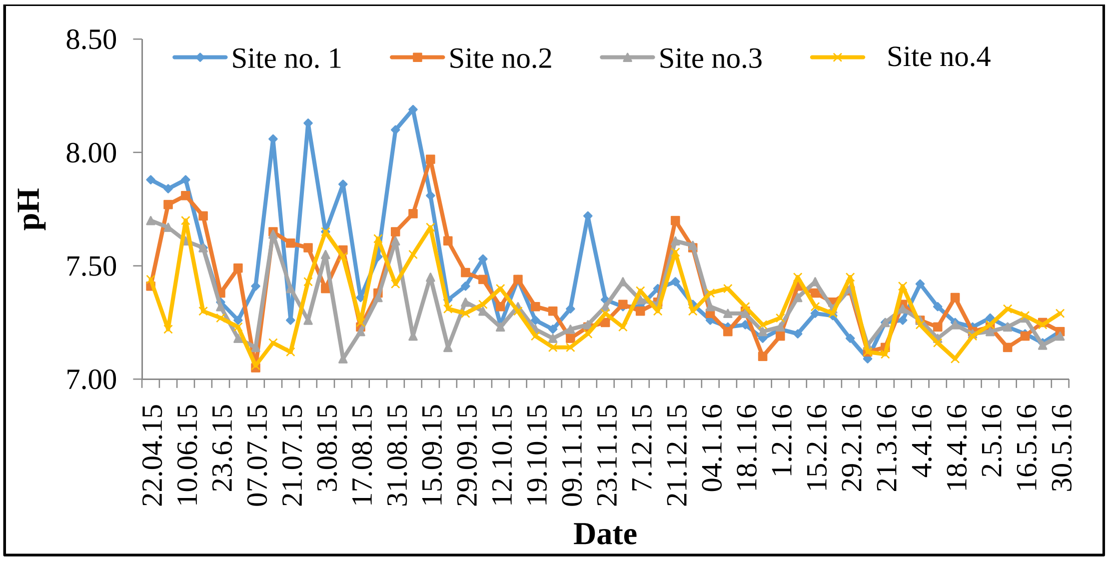

Fig. 4.5 pH values of groundwater samples at four sites

Fig. 4.6 Electrical conductivity (mhos/cm) values of groundwater samples at four sites

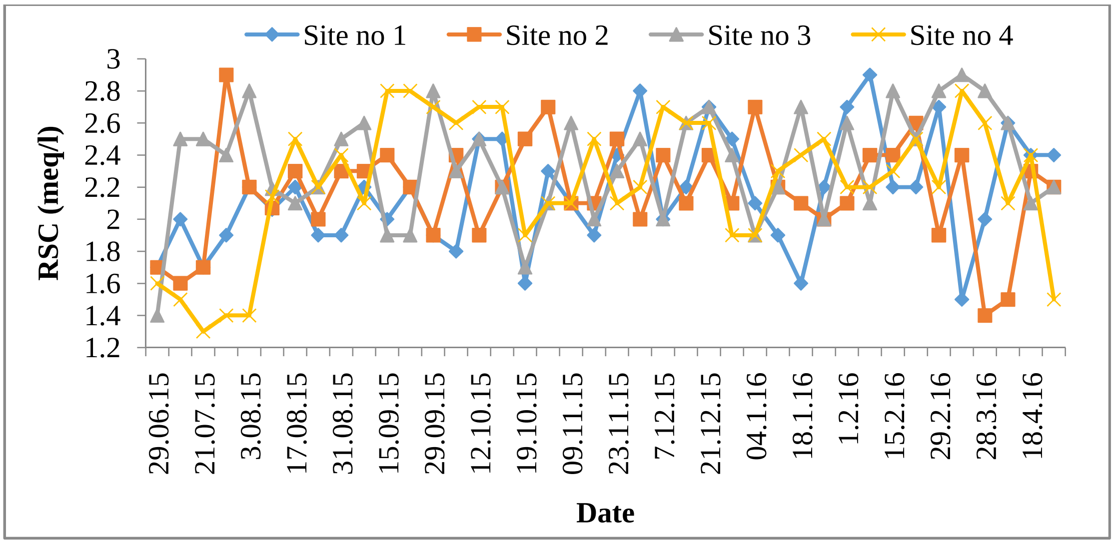

Fig. 4.7 RSC (meq/l) values of groundwater samples at four sites

The bacteriological analysis of recharged groundwater and canal water revealed that it was not within the permissible limits of drinking water standards (Table 4.2).

Table 4.2 Bacteriological quality analysis of water sample

S. No.	Location	Coliform organisms		Faecal Coliform/ E. coli detected/ Not detected
		Present/Absent	Most Probable Number index (<10/100ml)	
1	Site no 1	Present	240	Detected
2	Site no 2	Present	460	Detected
3	Site no 3	Present	240	Detected
4	Site no 4	Present	460	Detected
5	Canal Water	Present	1100	Detected

4.4 Recharging of Abandoned Wells

4.4.1 With and without gravel pack

Recharging rates of abandoned well was measured under two conditions. Initial recharge from these wells was without gravel pack i.e. the water directly diverted to the wells from filter pits. Recharge rate were observed with respect to time and observations were taken at different interval. The experiment was replicated for 15 times each, for both with and without gravel pack and the results are graphically represented in Fig. 4.8, 4.9, 4.10 and 4.11 for site 1, 2, 3 and 4, respectively. The results indicated the difference in their time for same volume of recharging water in both cases. Recharging time is reduced by gravel pack and increase the life of well. In all these wells, recharging after gravel pack were earlier 10 to 20 per cent of required time of same volume of water as compared to without gravel pack.

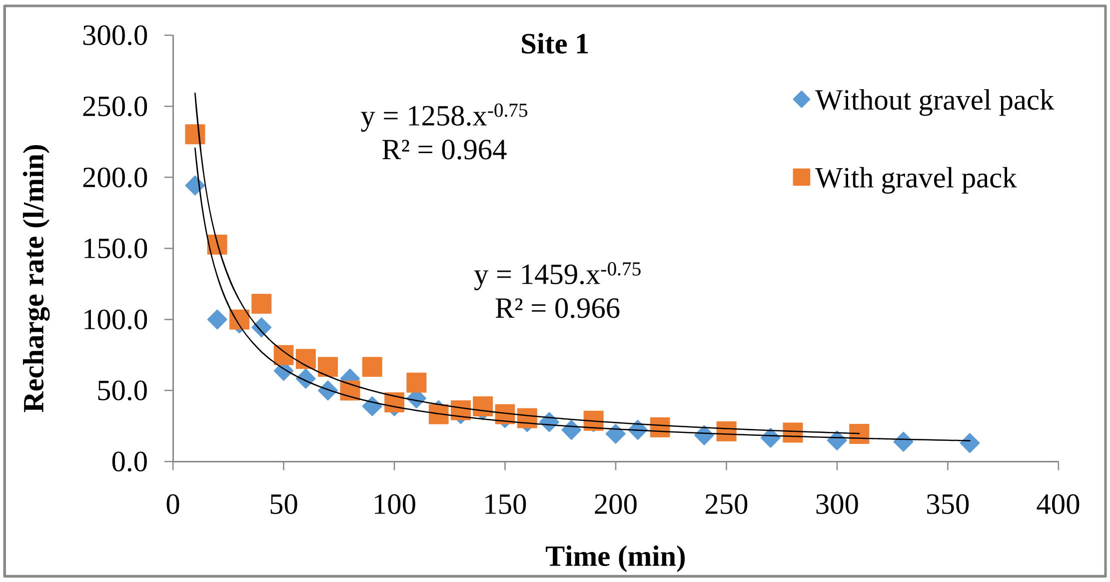

Fig. 4.8 Recharge rate before and after gravel pack at site 1

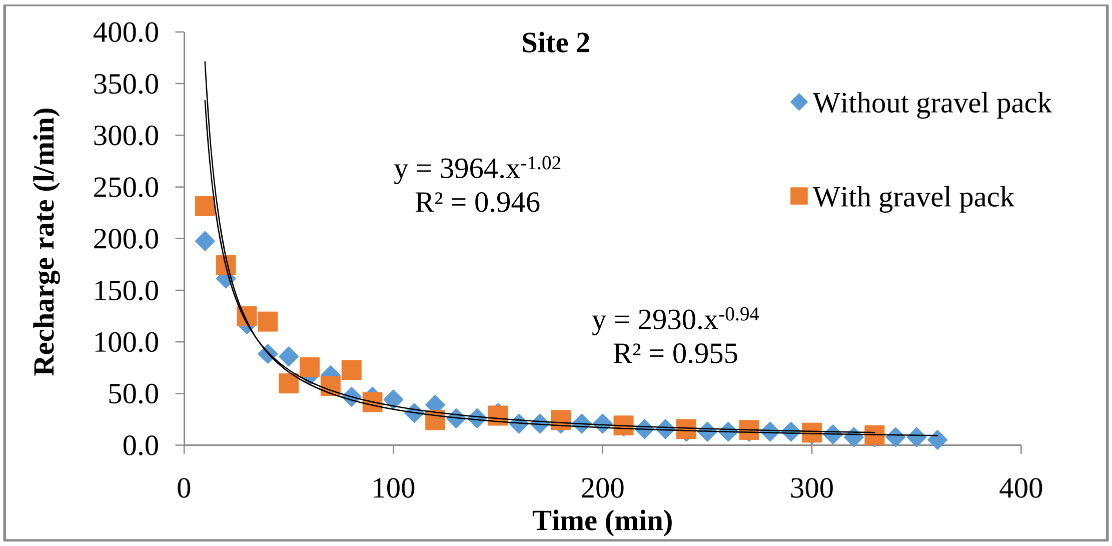

Fig. 4.9 Recharge rate before and after gravel pack at site 2

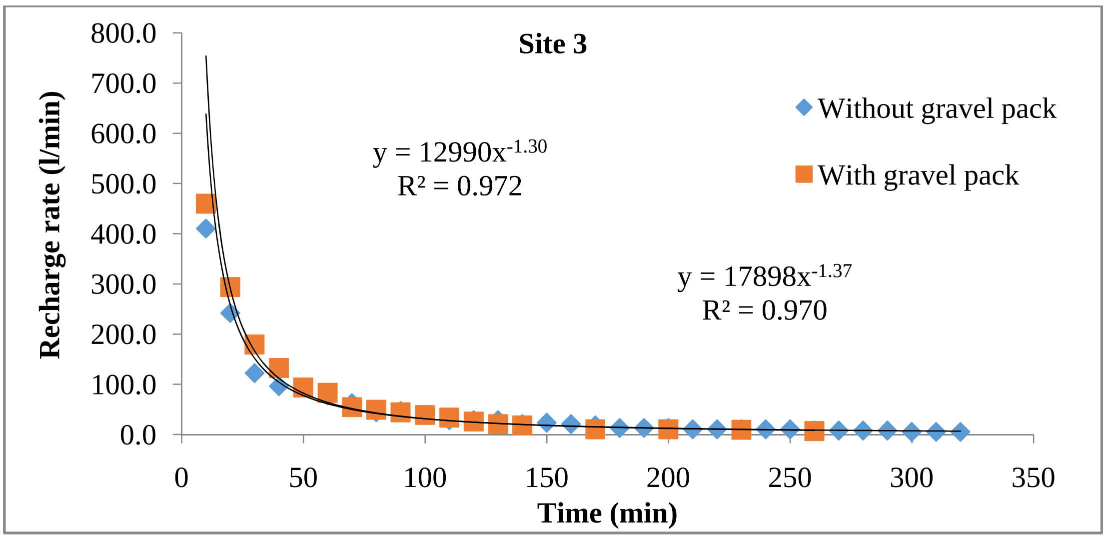

Fig. 4.10 Recharge rate before and after gravel pack at site 3

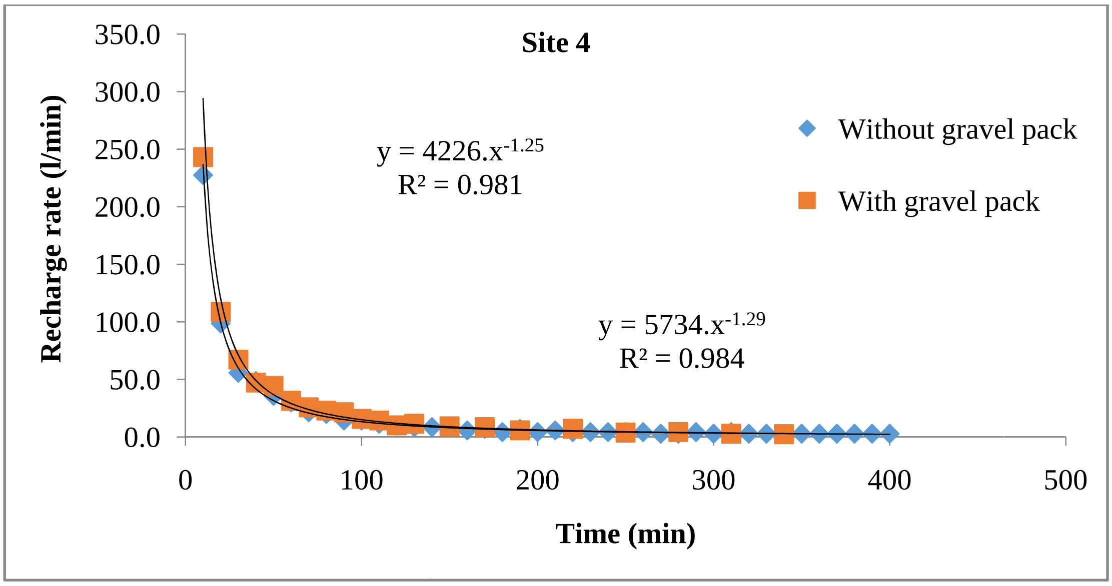

Fig. 4.11 Recharge rate before and after gravel pack at site 4

4.4.2 Under unsaturated and saturated conditions

Recharge rate of abandoned wells was reduced due to saturation of soil column in unconfined aquifer as shown in Table 4.3. At site 1, the recharge rate was initially high under unsaturated condition for first 100 min as shown in Fig. 4.12 and then it decreased due to partial saturation of the underlying soil with respect to time. After 10 to 15 times of recharging from the well, the aquifer underneath was fully saturated. The recharge rate was then reduced to half of unsaturated recharge rate. The recharge rate decreased from 390 l/min to 190 l/m due to saturation of the well. At site 2, the recharge rate of well was significantly reduced as shown in Fig. 4.13. The recharge rate decreased from 580 l/min to 210 l/min for unsaturated to saturated condition. Similarly at site 3 and site 4 the recharge rate decreased significantly as shown in Fig. 4.14 and Fig. 4.15.

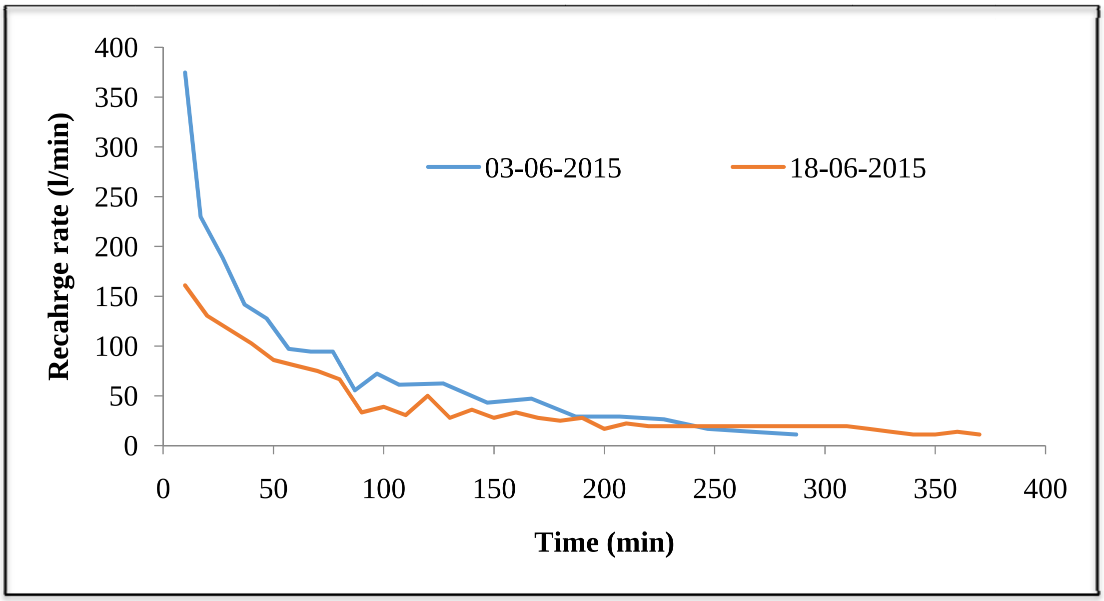

Fig. 4.12 Recharge rate of wells in saturated and unsaturated conditions at site 1

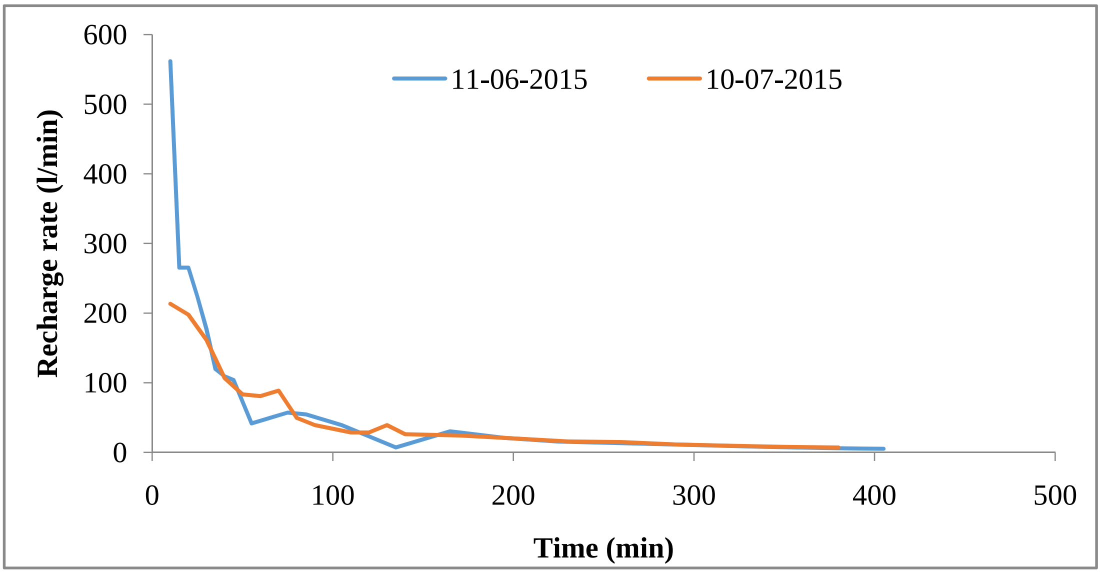

Fig. 4.13 Recharge rate of wells in saturated and unsaturated conditions at site 2

Table 4.3 Observed recharge rates at different time intervals

Time	Depth of water (m)	Depth of well (m)	Head (m)	Time interval (min)	Depth interval (m)	Recharge (m^3/min)	Recharge (l/min)	Recharge (l/sec)
11:00	0.76	8.31	-	-	-	-	-	-
11:10	1.52	8.31	7.55	10	0.76	0.211	210.9	3.51
11:20	2.10	8.31	6.79	10	0.58	0.161	160.9	2.68
11:30	2.55	8.31	6.21	10	0.45	0.125	124.9	2.08
11:40	2.85	8.31	5.76	10	0.30	0.083	83.2	1.39
11:50	3.15	8.31	5.46	10	0.30	0.083	83.2	1.39
12:00	3.40	8.31	5.16	10	0.25	0.069	69.4	1.16
12:10	3.65	8.31	4.91	10	0.25	0.069	69.4	1.16
12:20	3.84	8.31	4.66	10	0.19	0.053	52.7	0.88
12:30	4.01	8.31	4.47	10	0.17	0.047	47.2	0.79
12:40	4.18	8.31	4.30	10	0.17	0.047	47.2	0.79
12:50	4.33	8.31	4.13	10	0.15	0.042	41.6	0.69
1:00	4.46	8.31	3.98	10	0.13	0.036	36.1	0.60
1:10	4.60	8.31	3.85	10	0.14	0.039	38.8	0.65
1:20	4.74	8.31	3.71	10	0.14	0.039	38.8	0.65
1:30	4.83	8.31	3.57	10	0.09	0.025	25.0	0.42
1:40	4.92	8.31	3.48	10	0.09	0.025	25.0	0.42

1:50	5.01	8.31	3.39	10	0.09	0.025	25.0	0.42
2:00	5.11	8.31	3.30	10	0.10	0.028	27.7	0.46
2:10	5.20	8.31	3.20	10	0.09	0.025	25.0	0.42
2:20	5.28	8.31	3.11	10	0.08	0.022	22.2	0.37
2:30	5.35	8.31	3.03	10	0.07	0.019	19.4	0.32
2:40	5.43	8.31	2.96	10	0.08	0.022	22.2	0.37
2:50	5.51	8.31	2.88	10	0.08	0.022	22.2	0.37
3:00	5.58	8.31	2.80	10	0.07	0.019	19.4	0.32
3:10	5.64	8.31	2.73	10	0.06	0.017	16.6	0.28
3:20	5.71	8.31	2.67	10	0.07	0.019	19.4	0.32
3:30	5.78	8.31	2.60	10	0.07	0.019	19.4	0.32
3:40	5.84	8.31	2.53	10	0.06	0.017	16.6	0.28
3:50	5.90	8.31	2.47	10	0.06	0.017	16.6	0.28
4:00	5.97	8.31	2.41	10	0.07	0.019	19.4	0.32
4:10	6.04	8.31	2.34	10	0.07	0.019	19.4	0.32
4:20	6.10	8.31	2.27	10	0.06	0.017	16.6	0.28
4:30	6.17	8.31	2.21	10	0.07	0.019	19.4	0.32
4:40	6.22	8.31	2.14	10	0.05	0.014	13.9	0.23
4:50	6.27	8.31	2.09	10	0.05	0.014	13.9	0.23
5:00	6.31	8.31	2.04	10	0.04	0.011	11.1	0.18

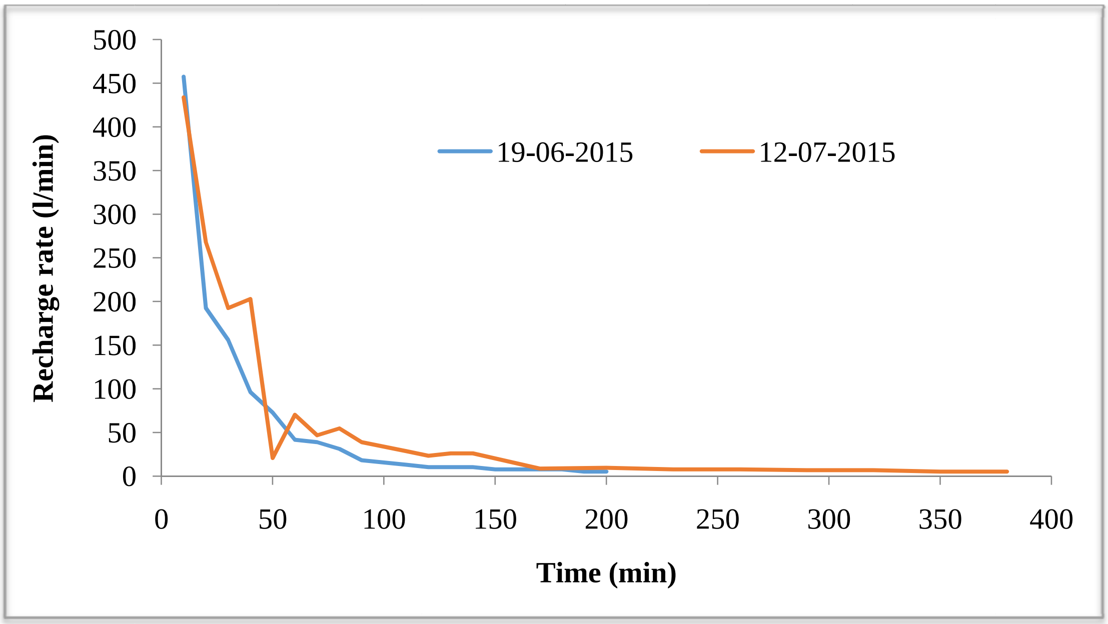

Fig. 4.14 Recharge rate of wells in saturated and unsaturated conditions at site 3

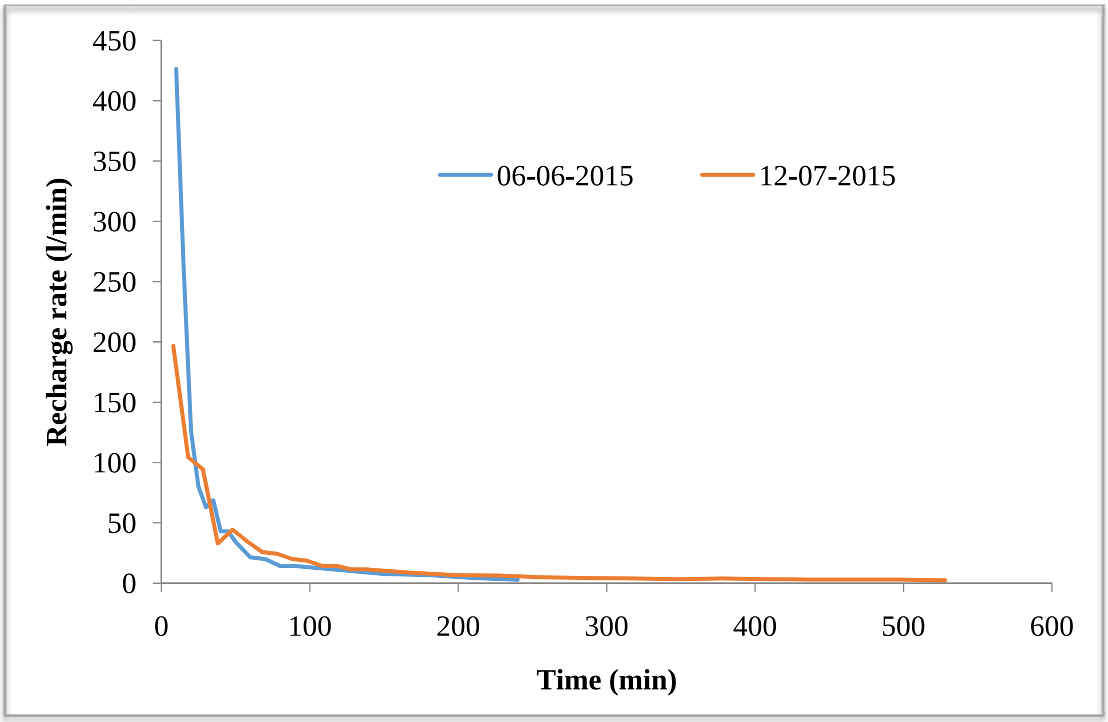

Fig. 4.15 Recharge rate of wells in saturated and unsaturated conditions at site 4

4.5 Statistical Analysis

The statistical analysis of the recharge rates without and with gravel pack, with respect to 5 hour recharging time, in four wells is shown in Table 4.4 and Table 4.5 respectively. Recharge rate before gravel pack and after gravel pack site 1, site 2, and site 3 non-significantly differ to each other, but the recharge rate at site 4 was significantly different from site1, site 2 and site 3 as indicated in Table 4.4, may be due to smaller diameter and depth of the well as compared other sites which resulted in low head.

Table 4.4 Hourly recharge rate at different sites before gravel pack

Time / Site	Recharge rate (l/min)				CD Value (0.05)
	1	**2**	**3**	**4**	
1st hour	81.0	81.7	75.4	31.5	16.31
2nd hour	44.0	40.1	26.9	12.0	7.96
3rd hour	35.5	25.2	12.3	8.2	5.39
4th hour	22.7	19.5	8.8	5.0	2.94
5th hour	16.5	13.0	6.6	4.0	2.62

Table 4.5 Hourly recharge rate at different sites after gravel pack

Time / Site	Recharge rate (l/min)				CD Value (0.05)
	1	2	3	4	
1st hour	81.02	81.65	75.41	31.48	16.31
2nd hour	44.02	40.11	26.88	11.96	7.96
3rd hour	35.52	25.25	12.31	8.25	5.39
4th hour	22.72	19.50	8.84	4.96	2.94
5th hour	16.52	12.97	6.59	4.01	2.62

4.6 Hydraulic Conductivity

Hydraulic conductivity of the site 1, site 2, site 3 and site 4 was 2.08, 3.00, 3.69 and 2.59 m/day respectively and is presented in Table 4.6. The high K value and low recharge rate at site 3 can be attributed to the fact that the side walls of the well were not properly lined and there may be some seepage from these well. Also the channel for water conveyance was not lined.

Table 4.6 Hydraulic conductivity at different sites

Sites	Hydraulic Conductivity (K) m/day	Specific Surface Area of wells (m^2)	Volume (m^3)
Site 1	2.08	2.774504	20.11515
Site 2	3.00	2.600234	16.38147
Site 3	3.69	2.628887	16.69343
Site 4	2.59	1.430663	7.797111

4.7 Impact of Recharge on Groundwater Table

Groundwater level depth at these four sites varied from 23.40 m to 25.31 m from ground surface during study period. There was very little impact of recharging on the water table at different sites. This may be due to the fact that a large portion of shallow aquifers have dried up and water has to travel a long distance to reach to groundwater, it was observed that the water table rose up to a maximum 10 cm due to recharging. The fluctuations in water table depth at four sites, with and without gravel pack are shown in Fig. 4.16(a, b) 4.17(a, b), 4.18(a, b) and Fig. 4.19 (a, b) respectively.

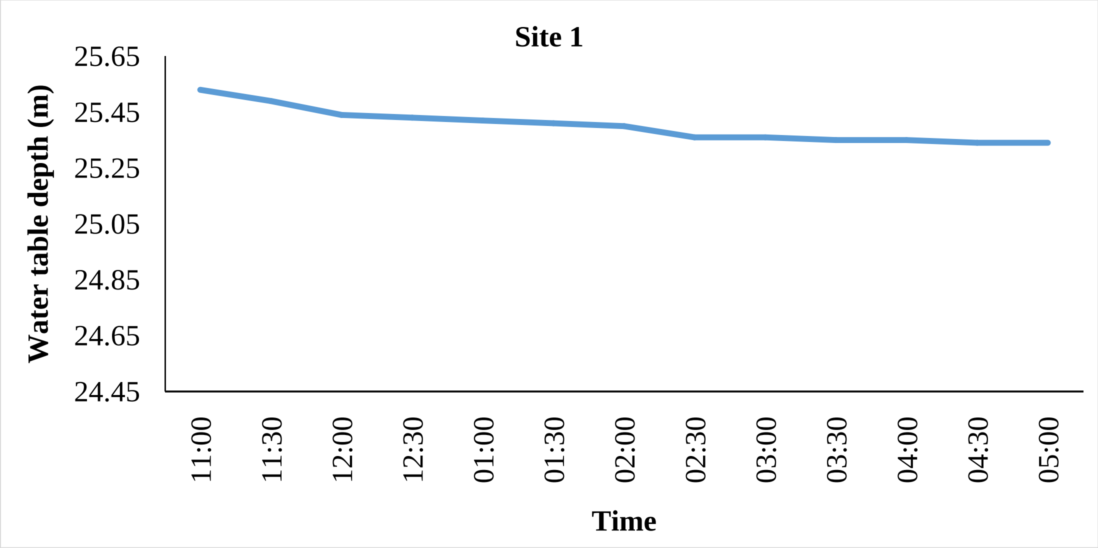

Fig. 4.16(a) Fluctuations in water table depth with gravel pack at site 1

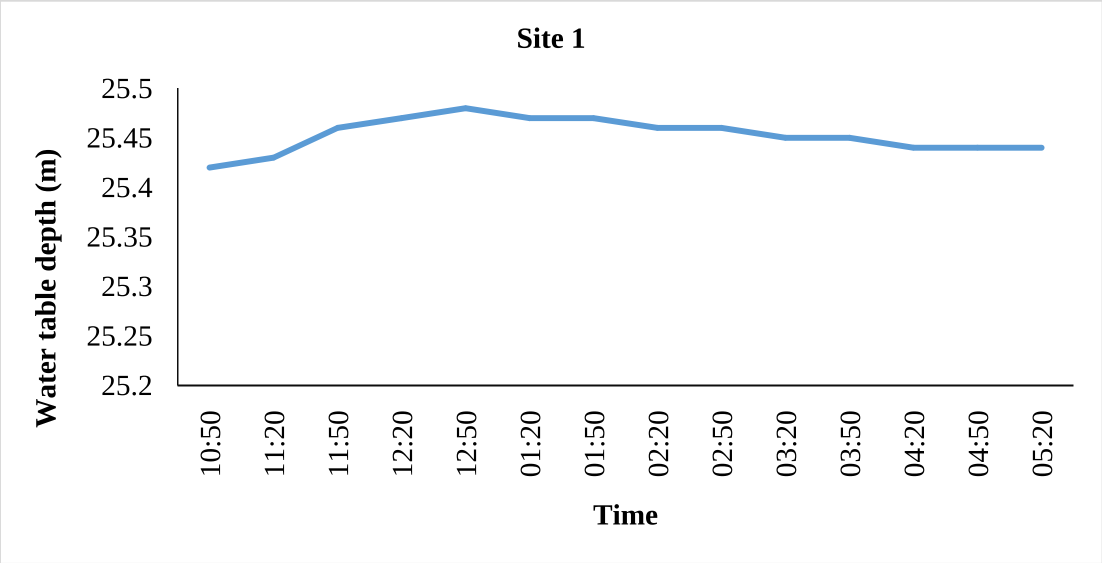

Fig. 4.16(b) Fluctuations in water table depth without gravel pack at site 1

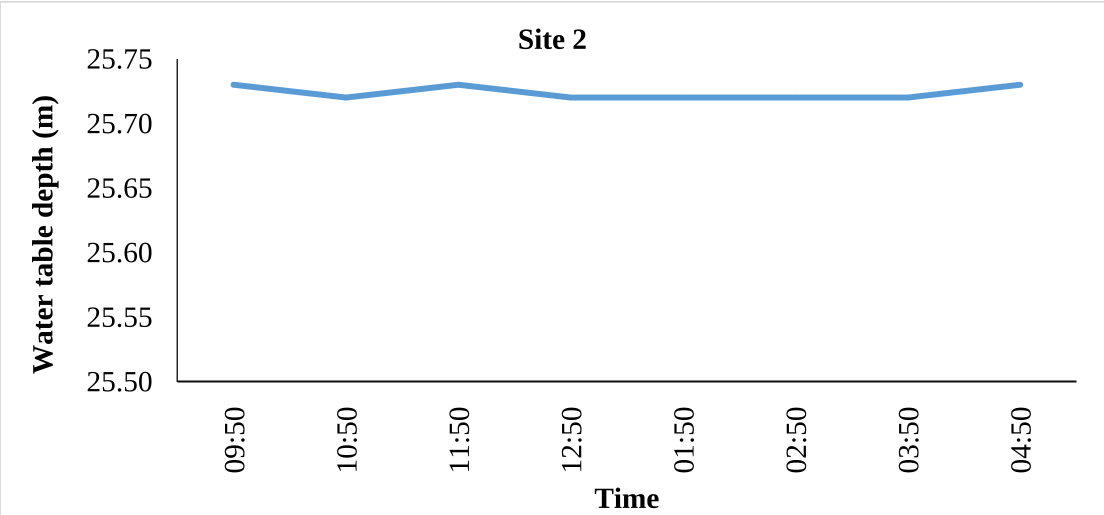

Fig. 4.17(a) Fluctuations in water table depth with gravel pack at site 2

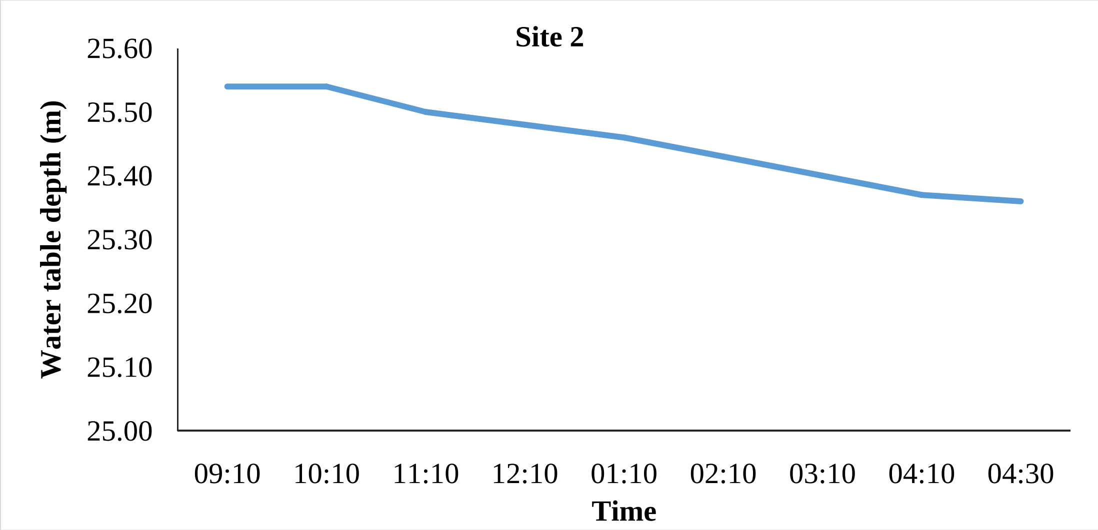

Fig. 4.17(b) Fluctuations in water table depth without gravel pack at site 2

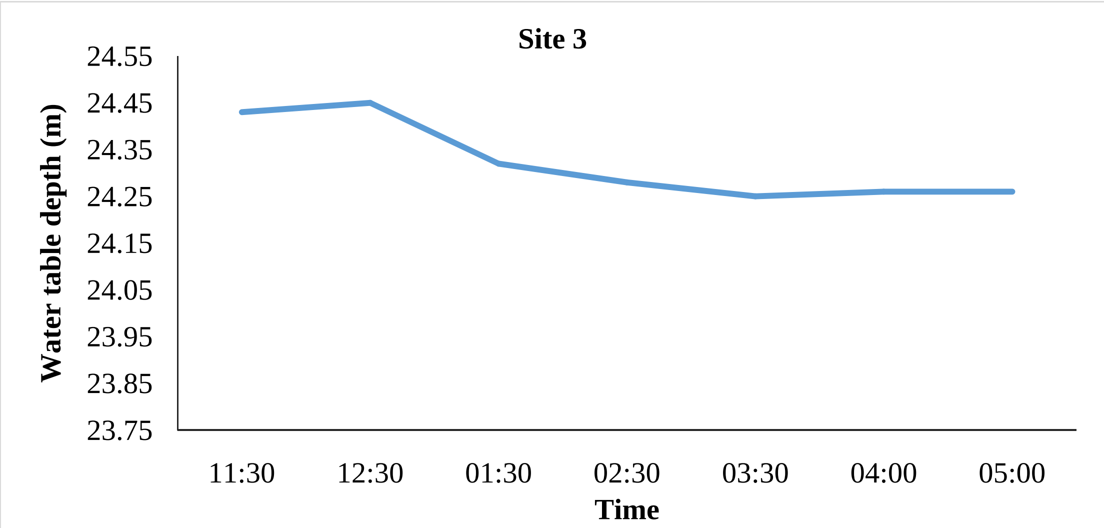

Fig. 4.18(a) Fluctuations in water table depth with gravel pack at site 3

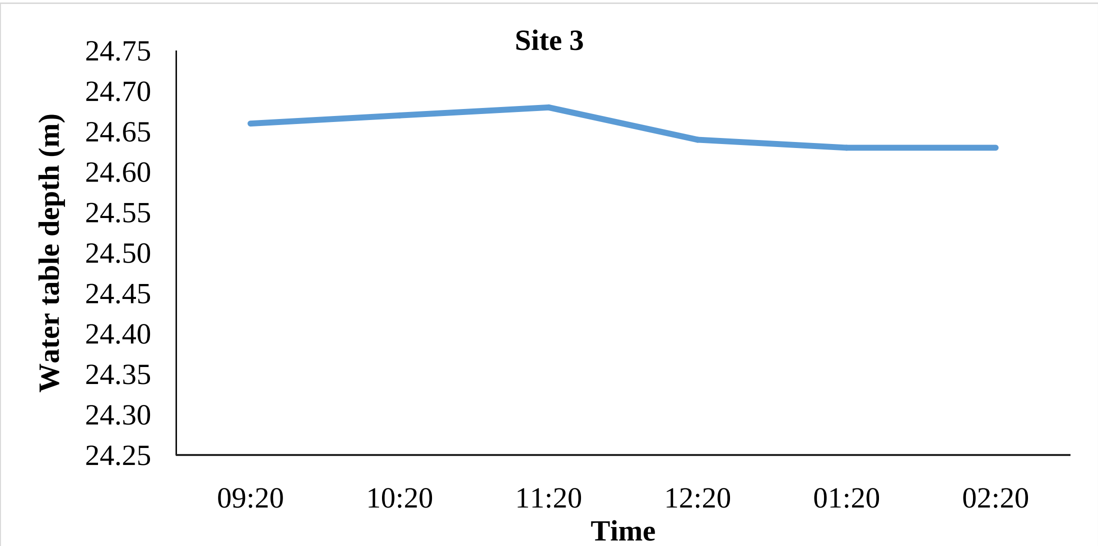

Fig. 4.18(b) Fluctuations in water table depth without gravel pack at site 3

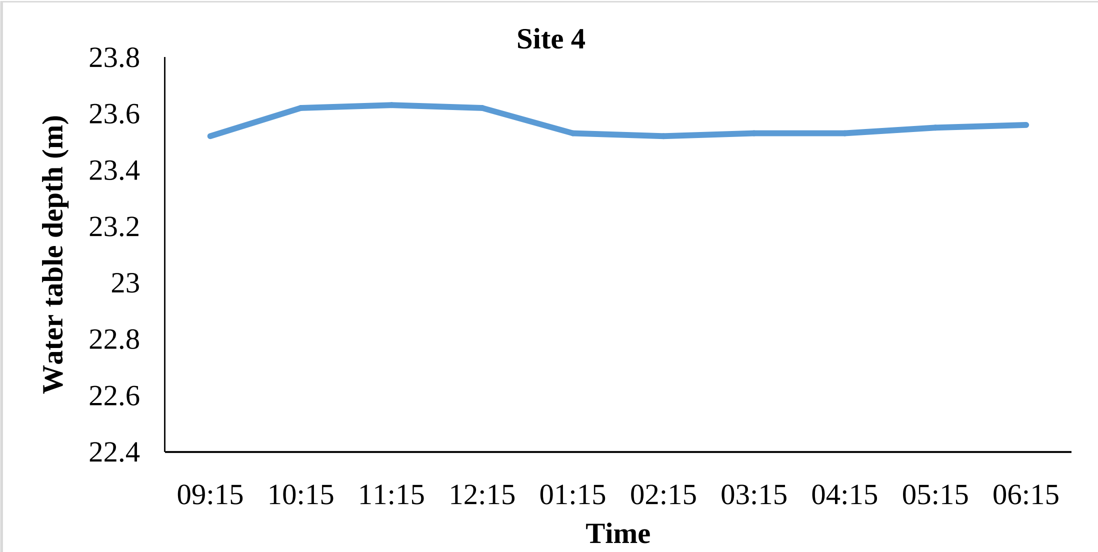

Fig. 4.19(a) Fluctuations in water table depth with gravel pack at site 4

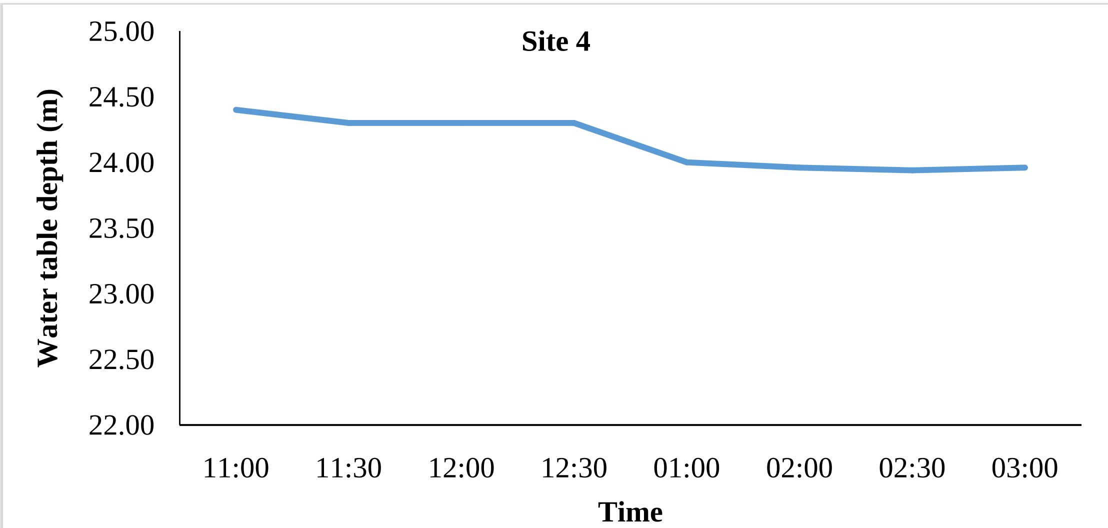

Fig. 4.19(b) Fluctuations in water table depth without gravel pack at site 4

CHAPTER V

SUMMARY AND CONCLUSION

In Punjab out of 98 percent irrigated area about 75 percent area is irrigated by groundwater and 25 percent by canal water. There has been overexploitation of groundwater in major part of state, which leads to progressive decline of water table. Due to continuous decline of groundwater level, the wells which were earlier used for withdrawal of groundwater have dried up and become abandoned. Artificial recharge is one of the water management techniques that can be used to replenish the groundwater reservoir. Therefore, the present study was undertaken to utilize these abandoned dug wells for groundwater recharge by diverting surplus canal water with and without gravel packs. Four different sites of abandoned well were used for recharging of groundwater with the objectives: (i) to estimate the recharge rate from abandoned dug well. (ii) to study the impact of recharge on the water table depth. The study was conducted at the research farms of department of Soil Science and department of Agronomy, PAU, Ludhiana. The existing wells were cleaned, renovated and modified for recharging of ground water. The observation wells were installed for monitoring of groundwater fluctuation and its quality parameters. Soil samples at different sites were analysed per cents sand, silt and clay. The water quality of canal water as well as groundwater was also analyzed during recharging period of ground water. Recharging was done with & without gravel pack and was replicated 15 times.

Based on this study following conclusions can be drawn:

(i) Under unsaturated condition recharges varies from 0.2 l/s to 7.67 l/s.

(ii) Maximum head at sites 1, 2, 3 and 4 are 7.36, 6.36, 6.40, 5.56 m respectively.

(iii) Recharge through surplus canal water improves overall quality of groundwater.

(iv) Change in time of recharge rate with or without gravel pack for some volume of water with gravel pack time reduced to 40 min to 80 min and it well improve the life of abandoned well, as silt and clay content will be absorbed by the gravel pack.

(v) Recharge rate of first three sites were non-significant whereas at site no.4 recharge rate was significantly lower at 5 % level of significance.

(vi) There was negligible effect on rise in water table due to recharging as it was done with limited volume of water and limited duration.

REFERENCES

Aggarwal R, Kaushal M P, Kaur S and Singh B (2009) Water resource management for sustainable agriculture in Punjab, India. *Water Sci Technol* **60**:2905-11.

Anonymous (1975, 2012) *Statistical Abstract of Punjab.* Directorate of Economics and Statistics, Government of Punjab, Chandigarh.

Bhattacharya A K (2010) Artificial ground water recharge with a special reference to India. *IJRRAS* **4**:214-21.

Bouwer H (1989) Estimating and enhancing groundwater recharge. *Groundwater recharge*. Pp 1-10. Balkema Publishers, Rotterdam, Netherlands.

Bouwer H (2002) Artificial recharge of groundwater: hydrogeology and engineering. *J Hydrology* **10**:121-42.

Brown R F and Signor D C (1974) Artificial recharge- state of the art. *Ground Water* **12**:152-160.

Brune G (1970) How much underground water storage capacity does Texas have? *Water Resources Bull* **6**:588-601.

CGWB (1994) Manual on Artificial Recharge of Ground Water. Ministry of water resources *Central Groundwater Board.*

CGWB (2012) Groundwater year book, ministry of water resources, Government of India, New Delhi.

Emily C, Edwards, Thomas H, Graham E, Fogg, Washburn B and Hamad H (2016) Assessing the effectiveness of drywells as tools for storm water management and aquifer recharge and their groundwater contamination potential. *J Hydrol* 539-53.

Goyal R K (2003) Bore Wells - A Boon for Tail End Users. Punjab Irrigation Department, RajuwalaSub Divisional Officer (Faridkot), E-mail: goyal_rkg2003@yahoo.com

Guo and James C Y (2003) Design of Infiltrating Basin by Soil Storage and Conveyance Capacities. *IWRA Int J Water* **28:**4.

Gupta S (2009) Ground water management in alluvial areas of Punjab. *J Bhu-Jal News* **24:**74-81.

GWREC (2014) Groundwater Resources Estimation Methodology. Report of the water

Resources Estimation Committee, Ministry of Water Resources Government of India. p.1047.

Hashemi H, Berndtsson R, Kompani-Zare M and Persson M (2013) Natural vs. Artificial groundwater recharge, quantification through inverse modelling. *Hydrol Earth Syst Sci* **17**:637-50.

Hassan M I and Ahmed S (2013) Assessment of Hydraulic Performance of Groundwater Recharge Techniques*. Int J Water Res Arid Envir***2**: 120-24, 2013 ISSN 2079-7079

Hira G S (2004) *Status of Water Resources in Punjab and Management Strategies. Workshop papers of groundwater use in North-West India*. Abrol I P, B R Sharma and G S Sekhon (eds). p. 1468.

Jain A K and Kumar R (2007) Water management issues – Punjab, North-West India. *Indo-US Workshop on innovative e-technologies for distance education and extension/ outreach for efficient water management,* ICRISAT, Patancheru/ Hyderabad, Andhra Pradesh, India. www.observerindia.com/cms/export/orfonline/.../ppt/o411-aljain.pdf (Accessed on 20-04-2014)

Kaledhonkar M J, Singh O P, Ambast S K and Tyagi N K (2003) Artificial Groundwater Recharge through Recharge Tube Wells. *IE (I) J A G* **84:**1-5.

Kaur S, Aggarwal R and Soni A (2011) Study of Water-Table behaviour for India Punjab using GIS. *Water Sci Technol* **63**:1574-81.

Khepar S D, Sondhi S K, Chawla J K and Singh M (2000) Impact of soil and water conservation works on ground water regime in Kandi Area of Punjab. *J Soil Water Conservation* **45**:182-89.

Lluria M R (2009) Successful application of Managed Aquifer Recharge in the improvement of the water resources management of semi-arid regions: Examples from Arizona and the South-western U.S.A. *Boletín Geológicoy Minero* **120**:111-20.

Magnus U, Igboekwe and Ruth A (2011) Groundwater Recharge through Infiltration Process: A Case Study of Umudike, South-eastern Nigeria. *J Water Res Protection* **3:**295-99.

Muthukrishnan A, Bhuvneswaran, Panneerselvam A and Alaguraja P (2013) Role of remote sensing and GIS in artificial recharge of the groundwater aquifer in the

Shanmuganadi Sub Watershed in the Cauvery River Basin, Trichirapali District, Tamil Nadu. *Int J Applied Sciences Engg Res* **2**:2277-8442.

Narjary B, Kumar S, Kamra S K, Bundela D S and Sharma D K (2014) Impact of rainfall variability on groundwater resources and opportunities of artificial recharge structure to reduce its exploitation in fresh groundwater zones of Haryana, *Current Sci* **107**:1306-8.

Narula A (2014) Feasibility of Recharge Shafts/Injection Wells for Groundwater Recharge in Patan District, Gujarat, India**.** *Int J Adv Res Engg Applied Sciences* **3**:7, ISSN: 2278-6252.

Patel P and Desai M D (2010) Artificial Ground Water Recharge Field Study. *Int J Adv Engg Tech*.

Ravichandran S, Kumar S and Singh L (2011) Selective techniques in artificial ground water recharge through dug well and injection well methods. *Int J Chem Technol Res* **3**:1050-53.

Santosh D T, Satishkumar U, Shashidhara N, Ravikumar H and Chayadevi K (2011) Watershed Management of Unkal watershed, Dharwad district, Karnataka to Enhance Groundwater Resource –A Case Study. *Int J Agr Environ Biotechnol* **4**:175-80.

Sayana V B M, Arunbabu E, Kumar M L, Ravichandran S and Karunakaran K (2010) Groundwater responses to artificial recharge of rainwater in Chennai, India: a case study in an educational institution campus*. Indian J Sci Technol* **3**:124-30.

Singh K (2006), Fall in Water Table in Central Punjab- How Serious? Punjab State Farmers Commission (PSFC), Government of Punjab.

Sridhana K, Sathyanarayana D and Reddy A (1990) Analysis of flow near a dug well in an unconfined aquifer. *J Hydrol* **119:**89-10.

Suter M and Harmeson R H (1960) Artificial Ground-water recharge at Peoria, Illinois *Bulletin 48*, Department of Registration and Education, Illinois State Water Survey, Urbana.

VITA

Name of the student	Mr. Palwinder Singh
Father's name	S. Ranjit Singh
Mother's name	Smt. Manpreet Kaur
Nationality	Indian
Date of Birth	20-12-1990
Permanent address	V.P.O. Rori Kapura, Tehsil Jaito, District Faridkot-151202, Punjab

EDUCATIONAL QUALIFICATION

Bachelor's Degree	B. Tech. (Agriculture Engineering)
University and Year of award	Punjab Agricultural University, Ludhiana 2013
OCPA	6.19
Master's Degree	M. Tech. (Soil and Water Engineering)
University and Year of award	Punjab Agricultural University, Ludhiana 2017
OCPA	6.71
Title of the Master Thesis	Evaluation of abandoned wells for groundwater recharge