DESIGN AND EVALUATION OF A HORIZONTAL FILTER UNIT FOR GROUND WATER RECHARGE THROUGH ABANDONED TUBE WELL

by

JOMOL T JOSEPH

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

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JOMOL T JOSEPH

(2014 – 18 – 104)

THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY TAVANUR, MALAPPURAM -679573

KERALA

2016

DECLARATION

I hereby declare that this thesis entitled **"Design and Evaluation of a Horizontal Filter Unit for Ground Water Recharge Through Abandoned Tube Well"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Place: Tavanur **Jomol T Joseph**

Date: **(2014-18-104)**

CERTIFICATE

Certified that this thesis entitled **"Design and Evaluation of a Horizontal Filter Unit For Ground Water Recharge Through Abandoned Tube Well"** is a record of research work done independently by **Ms. Jomol T Joseph (2014-18-104)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Tavanur,
Date:

Dr. Rema K P.
(Major Advisor, Advisory Committee)
Professor, Dept. of IDE,
KCAET, Tavanur.

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Jomol. T. Joseph.,** a candidate for the degree of **Master of Technology in Agricultural Engineering**, agree that the thesis entitled **“Design and Evaluation of a Horizontal Filter Unit For Ground Water Recharge Through Abandoned Tube Well”** may be submitted by **Ms. Jomol. T. Joseph (2014–18–104)**, in partial fulfillment of the requirement for the degree.

Dr. Rema, K.P.
(Chairman, Advisory Committee)
Professor, Dept. of IDE,
KCAET, Tavanur

Dr. Sasikala, D.
(Member, Advisory Committee)
Professor & Head, Dept. of IDE,
KCAET, Tavanur

Dr. Visalakshi, K.P.
(Member, Advisory Committee)
Professor & Head, Dept. of Agrl. Engg.
CoH, Vellanikkara, Thrissur

Dr. Asha Joseph
(Member, Advisory Committee)
Professor, Dept. of IDE
KCAET, Tavanur

Dr. Sureshkumar, P.K.
(Member, Advisory Committee)
Associate Professor,
Dept. of Agrl. Engg**,**
CoH, Vellanikkara, Thrissur

EXTERNAL EXAMINER

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Dedicated to

My Family

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Percentage
&	:	And
/	:	Per
+	:	Plus
<	:	Less than
>	:	Greater than
_	:	Minus
ANOVA	:	Analysis of variance
ASR	:	Aquifer storage and recovery
ASTR	:	Aquifer storage transfer and recovery
BCM	:	Billion cubic meters
C & B	:	Co – operation and banking
CSSRI	:	Central Soil Salinity Research Institute
cm/s	:	Centimeters per second
cm/d	:	Centimeters per day
CGWB	:	Central Ground Water Board
cm	:	Centimeter
CoH	:	College of Horticulture
cm^3	:	Cubic centimeter
cm^2	:	Square centimeter
Ca	:	Calcium
Cl	:	Chloride
$CaCO_3$	:	Calcium carbonate
cm/h	:	Centimeter per hour
DMRT	:	Dunkan’s Multiple Range Test
dS/m	:	Decisiemens per meter
et al.	:	And others

etc.	:	Etcetera
EC	:	Electrical Conductivity
FCRD	:	Factorial completely randomized design
Fe	:	Iron
GEC	:	Ground water estimation committe
g	:	Gram
ha	:	Hactare
ha-m	:	Hectare meter
HRF	:	Horizontal roughing filter
HE	:	Hydraulic efficiency
i.e.	:	That is
IS	:	Indian standard
IWDP	:	Integrated watershed development programme
INR	:	Indian national rupee
KAU	:	Kerala agricultural university
km^2	:	Square kilometer
km	:	Kilometer
KCl	:	Pottasium chloride
lps	:	Litre per second
ml	:	Milli litre
m^3	:	Cubic meter
M km^3	:	Million cubic kilometer
ml	:	Milli Litre
m	:	Meter
mm	:	Milli Meter
min	:	Minute
mg/l	:	Milligram per litre
m/h	:	Meter per hour

m/s	:	Meter per second
m^3/s	:	Cubic meter per second
mm/h	:	Millimeter per hour
mS	:	Milli Siemens
Mg	:	Magnesium
M	:	Molar
NTU	:	Nephelometric turbidity units
NaCl	:	Sodium chloride
NO_3	:	Nitrates
Ohm-cm	:	Ohm centimeter
p	:	Probability
ppm	:	Parts per million
ppt	:	Parts per trillion
PVC	:	Poly vinyl chloride
RARS	:	Regional agricultural research station
Rs	:	Rupees
s	:	Second (s)
Sl.	:	Serial
SO_4	:	Sulphate
TDS	:	Total dissolved solids
TS	:	Total solids
TSS	:	Total suspended solids
USBR	:	United states bureau of reclamation
UV	:	Ultraviolet
v/s	:	Versus
yr	:	Year
µS/cm	:	Micro Siemens per centimeter

CHAPTER-1

Introduction

CHAPTER I

INTRODUCTION

Water is essential for all forms of life and is the fundamental resource for human survival and socio economic development as well as for maintaining intact ecosystem. Water resources pose the greatest challenge due to variation in spatial and temporal availability, over exploitation and pollution. Growing water scarcity and competing water demands are expected to widen the gap between water supply and water demand in future.

The total quantity of water in the earth is estimated to be around 1386 Million cubic kilometres (M km^3). About 96.5 per cent of this water is contained in the oceans as saline water. Subsequently just around 41 M km^3 of fresh water is accessible out of which 31.4 M km^3 is present in the polar districts, mountains and ice sheets in solidified state. About 70 per cent of the fresh water consumed worldwide is used for irrigation. Only 20 per cent of fresh water is being utilized for industrial purposes (Gleick, 2013). But last decade has witnessed a dramatic shift in the priorities of water allocation and development. Due to the increased intense competition for water among various developing sectors, water needs of agriculture is shifted to other sectional water uses. The major reason for the shift is due to the high economic advantage of industrial and urban sections.

India is the second most populated nation in the world, with a population more than 1.32 Billion as in 2015 and has an agricultural based economy. It has 2.45 per cent of the total land area of the world, 16 per cent of the world population and is estimated to be endowed with about 4 per cent of world's water resources. Incident rainfall in the country is 1170 mm. Including snowfall along with precipitation corresponds to water resource capacity about 4000 Billion Cubic Meters (BCM). Out of this, around 1869 BCM is predictable as the average annual flow in rivers. On account of various limitations, only about 1122 BCM of water is estimated as annual utilizable water, having surface water resource component of 690 BCM and groundwater component of 432 BCM (Gangwar, 2013).

Groundwater is a fundamental asset that fulfils around 60 per cent irrigation and 80 per cent drinking water needs of India. In spite of the critical role of groundwater in balancing out Indian agriculture, its unpredictable use has brought about fast decrease and degradation of this essential common asset. Groundwater levels in various parts of India are declining at an alarming rate, because the country is lacking adequate recharge of aquifers in scarcity areas, where it has been used for irrigation, manufacturing and drinking water requirements. As per the ministry of water resources, around 56 per cent of the wells which are examined to keep a tab on groundwater level indicated drop in its level in 2013 as compared to the average of previous 10 years. Exhausting groundwater level will be a serious issue if one focus on the future demands of water in India. It is expected that the country is in a necessity of 1,175 BCM of water annually by 2050; India has at present capability of 1,122 BCM of exploitable water with 691 BCM coming from surface water resources and remaining from groundwater resources (CGWB, 2014).

Kerala state lies as a narrow strip of land bordered by Western Ghats on the eastern side and the Arabian Sea on the western side in the south west corner of India. In Kerala, the mean annual rainfall received is 3000 mm. The total number of rainy days in a year is 126. Although rainfall received in Kerala is considerable than the national average, only very little is utilized for productive purposes. The topography of the state is such that the average width is only 70 km with a length of 700 km. Within this narrow strip of land, we have regions lying few meters below mean sea level and peaks with an altitude of 2695 m above mean sea level. This undulating topography is the leading factor for water loss to the sea. The groundwater availability during the peak requirement period (Dec-May) has been found to be meagre for domestic and agricultural purposes. This is mainly on account of the large dependence on groundwater in rural areas and resultant high well density, where the spacing between pumping wells is less than 50 metres.

Over the years Kerala has gradually progressed towards a man-made water management crisis.

A state, which had more than 50,000 Million cubic meter of fresh water available in its 44 rivers, 900 odd ponds and 300 cm rainfall previously, is now under water stress in one third of its habitation. Worse than this, the 2011 national census figures indicate that only 41 per cent of Keralites have access to safe public water supplies. In rural area, 70 per cent or more of the inhabitants depends on well water which is polluted by intestinal coliforms, which undoubtedly cross pollutes from the seepage leak outs from the pits used for disposing human excreta. Water is turning out to be the limiting factor in the Kerala's development activities, having potential to overturn many of the social achievements we are proud off.

The Central Ground Water Board (CGWB) have analysed 10,219 wells across the country and concluded that 5699 wells had experienced water table decline during the testing period. The data also revealed that 71 per cent wells in Kerala also exhibited a fall in groundwater level. It is estimated that Kerala needs 48600 Billion litres of water in 2021 but the potential is only 47332 Billion litres. In order to recoup the shortage of these 1268 Billion litres, scientists and technicians need to understand, plan, and manage augmentation of groundwater recharge artificially to control such fast depleting groundwater tables. By considering the impacts of climate change also along with this situation, chances are there for this crisis to enhance. Thrissur, Malappuram, Palakkad and Ernakulam are the districts lacking enough water to meet their demand in the sequential order of ranking followed by Trivandrum, Kollam, Kozhikode, Alappuzha, Kannur, Kottayam, Pathanamthitta, Kasargod, Idukki and Wayanad districts. Kerala stands in third position among the states whose groundwater level has been lowered more than 70 per cent (CGWB, 2013).

Quality of groundwater is as important as its availability in determining its suitability for various uses. Chemical quality of groundwater is controlled by the presence of various chemical constituents present in it. Various standards are available for determining quality of ground water for agriculture, drinking, and industrial water uses. Fluorides, Nitrates and Chlorides are the common groundwater pollutants seen in Kerala.

The rate of groundwater level decline and the quality of groundwater can be improved to some extent by enhancing groundwater recharge using excess rainfall. Groundwater recharging may be natural or artificial. Artificial groundwater recharge is a method by which the depleted groundwater reservoir is replenished at a rate higher than the rate of natural recharge. The important considerations for successful implementation of artificial recharge schemes include availability of aquifer capacity and availability of surplus monsoon runoff.

Pilot project studies of CGWB indicate that percolation tanks, check dams, recharge shafts, and subsurface barriers are effective in augmenting groundwater resources in hard rock areas of Kerala, Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh and Maharashtra. Recharge trenches, recharge shafts and recharge tube wells are found to be most suitable groundwater recharge structures. Regular and proper maintenance of structures is a necessary prerequisite for the success of any artificial recharge scheme (CGWB, 2000).

Artificial recharge is a strategy of directed movement of surplus surface runoff through a constructed recharge structure into an exhausted aquifer. In order to avoid clogging of the well and to ensure that pollutant free water is recharged into the aquifer; an efficient filtering unit must be incorporated with recharge structures. The filtration unit must perform efficiently to get maximum benefits from the installed recharge structures.

Abandoned and exposed tube wells are a common sight in Kerala. Around 10.5 lakh abandoned open wells and tube wells are present in Kerala (Sreeraj, 2016). These unplugged or improperly plugged abandoned wells pose a serious threat to human life. So it is better to utilise these abandoned wells as recharge structures in order to control the depleting ground water table. According to the

CGWB district brochure 2015, the proposed study area in the research plot of the Nodal Water Technology Centre; KAU campus was identified in the sub-critical region of the Thrissur district considering the groundwater depletion scenario. It was recommended that all the over exploited and semi critical blocks may be given immediate attention for implementing artificial recharge schemes through state and central Governments. The site has a tube well dug by State Ground Water Department and is now abandoned due to lack of enough yields. In the campus, the surface water resources are utilized fully and usually get dried in summer seasons. Hence to meet the irrigation water needs it is essential to depend on alternate sources like groundwater. In this context, the study aims at conducting a feasibility analysis of utilizing this abandoned tube well in the site as an artificial recharge structure with proper filtration units to improve the groundwater potential of the area.

The specific objectives are:

1) Design and development of a horizontal filter unit with alternate filter media for treating storm water runoff.
2) Performance evaluation of the developed filter for hydraulic and pollutant removal efficiency.
3) Installation of the horizontal filter with selected media for recharging through the abandoned tube well.

CHAPTER-2

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Groundwater extraction has increased tremendously in the past few decades. Inappropriate groundwater management strategies have lead to the drawdown of groundwater level and degradation of its quality. Declination of groundwater table and pollution of the valuable water resource causes great hike in both social and economic cost. Thus, artificial groundwater recharge with good quality water is the potential need of the present era.

This study focuses on the design and development of a horizontal filter unit to recharge ground water through an abandoned tube well. Some of the literature relevant to the study are reviewed and presented in this section under the following sub headings.

2.1 GROUNDWATER RECHARGE ESTIMATION

Sophocleous (1992) has done a 6-year recharge study in Great Band Prairies of Central Kansas. By the statistical analysis, recharge events lasting for 5-6 days was determined in which 3-4 days were precipitation days with overall precipitation of 83 mm. He also reported that the most important parameters influencing recharge were total annual precipitation, soil-profile, and water storage during spring months, and shallowest depth to water table during the same period and spring time rainfall rate.

Gowda *et al.* (2000) estimated annual groundwater recharge in the Peddavanka watershed, Anantapur district, Andhra Pradesh, based on the methods recommended by Groundwater Estimation Committee (GEC) and CGWB India. The annual groundwater recharge was measured from the average annual rainfall, recharge through water bodies and recharge through applied irrigation. The annual groundwater draft was estimated based on the number of wells present in the watershed and the extent of area irrigated.

Scanlon *et al.* (2002) used different techniques such as tracer technique and physical technique to estimate groundwater recharge. They used theoretical models to evaluate sensitivity of recharge estimates on various parameters and to predict the effect of changes of climate and land use on recharge rates.

Chand *et al.* (2005) displayed a straightforward system to quantify groundwater recharge by using neutron depth moisture gauge under in situ conditions. Storativity values of the aquifer condition were evaluated in the Hayatanagar micro-watershed by utilizing soil moisture content and augmentation in water table of the district. Utilizing the normal estimations of the water table depth, the calibrated storativity value was got. It was utilized to interpret the water table rise in rainy conditions to measure the groundwater recharge.

Martin (2005) conducted a detailed recharge study in the Atankwidi basin in the semi-arid Sudan-Savanna climate zone of Ghana. The basin covers 275 km^2 and has a mean annual rainfall of 990 mm. Three methods, namely, water table fluctuation, isotope analysis and the chloride mass balance were used to estimate the recharge of groundwater in the basin. The results showed considerable variation in recharge, not only between wet and dry years but also from one location to another. The recharge ranged from 2 to 13 per cent of the mean annual rainfall; the long-term mean was obtained to be 6 per cent.

Kumar *et al.* (2007) conducted a study on environmental isotopes (stable, radioactive) used in conjunction with hydrogeology, hydro-chemistry and in-situ physico-chemical parameters to assess the attainment of artificial recharge measures. The investigation concluded that the modern day natural recharge to the tertiary aquifers is a slow process. With given years rainfall reaching water table and the recharge through pilot-scale artificial means is low quantity, hence not effective. However, a comparative study indicated that the suitable river for implementing large-scale artificial recharge measures could be the north bounded ephemeral river (Manimutharu) rather than the south one (Sarugani).

Ravi *et al.* (2007) assessed the groundwater recharge in the Noyyal river basin, Coimbatore. They made an attempt to estimate recharge in the Noyyal river basin area by water level fluctuation method. For the study, the Noyyal basin was subdivided into upper Noyyal, Avanashi and lower Noyyal sub-basins. It comprises the entire drainage basin area of the Noyyal river (3,510 km^2), a tributary of the Cauvery river, which flows eastward and joins the Bay of Bengal. In this basin, 13 rain gauge stations were monitored for annual rainfall, while 48 observation wells were monitored for monthly water level fluctuations from 1998-2005. The average annual rainfall recorded from the stations is found to be 641.51 mm. They concluded that the recharge was in the range of 8 to 15 per cent of the annual rainfall throughout the Noyyal river basin.

Raviraj *et al*. (2007) assessed the effectiveness of recharge structures in improving the groundwater situation in the Kodangipalayam watershed of Palladam block of Coimbatore district. The baseline survey such as mapping of the geology and the hydrogeologically significant features, topographical surveys to delineate the catchments of the structures etc were done. It was estimated that the Karanampettai structure captured 80 per cent of the runoff within its catchment. It was also observed that recharge was increased by 30 per cent by recharge structures whereas only 6 per cent was by natural recharge.

Singhal *et al.* (2010) made an attempt to delineate aquifer in the piedmont zone of Himalayan foothills region in Pathri Rao watershed, Haridwar district, Uttarakhand, by using combined geophysical and hydrogeologic techniques. By nuclear isotope studies of the area, estimation of groundwater recharge and its relative age was done. It was found that the recharge rate into the aquifers is in the order of 19 per cent and the stage of groundwater depletion in the watershed is 164 per cent indicating critical over-exploitation of groundwater.

Gontia *et al.* (2011) estimated the natural groundwater recharge for hard rock area of Jamka micro-watershed in Gujarat by using five empirical equations. Various statistical parameters such as standard deviation, coefficient of variation, coefficient of skewness, coefficient of Kurtosis, mean etc. were calculated for the estimation of recharge percentage by empirical relationships using rainfall data from 1970 to 2007 annually.

Kumar *et al.* (2011) called attention to the conceivable areas for development of water harvesting structures in the Sanjai Watershed of Jharkhand state by utilizing remote sensing and GIS strategies. The site was found suitable for the groundwater recharge structures utilizing GIS examination over the routine overview. Recommended structures for groundwater recharge for the area are rock bunds, check dams, percolation tanks and recharge pits and wells and subsurface dykes were proposed as needed.

Bhalerao *et al.* (2013) discussed various aspects regarding the artificial recharge of groundwater like essential elements to be well–thought-out for artificial recharge, benefits and drawbacks of artificial recharge, identification of recharge regions, sources of water for recharge, artificial recharge projects, different methods of artificial recharge, process and maintenance, etc.

2.2 GROUNDWATER QUALITY

Ballukraya *et al.* (2002) proposed a set of conclusions and suggestions to arrest the falling water table based on the case study in over-exploited zone near Namakkal district, Tamil Nadu. The study reveals that one of the prime reasons for over-exploitation of groundwater was the supply of free electricity to the agricultural sector. Over-exploitation of ground water results in crucial circle of lowered water levels, decrease in irrigated agricultural area, groundwater contamination and decline in groundwater availability in future.

Sivakumar *et al.* (2011) made an effort to survey the effects of urbanization exercises on the ground water quality in Amaravathy River Basin at Karur. Drinking water quality (IS: 10500) of monsoon season was better than pre monsoon season.

Adhikari *et al.* (2013) studied the effect of water harvesting structures on groundwater recharge and water quality in a watershed situated in a semi-arid region of Andhra Pradesh, India. Results show that the critical value of rainfall for ensuring 1 mm possible recharge is 61 mm. Potential recharge is only 3 per cent of total annual rainfall expected. Water analysis showed that except pH, all other water qualities reached desirable limits in close vicinity (<100 m) to the water harvesting structures.

Krishnaraj *et al.* (2013) conducted an investigation on calculation of groundwater quality in Karur square of Tamil Nadu. 25 water samples were collected and analysed for physical and chemical parameters. The study displayed that each parameter is significantly contributing to the water quality changes in the study area.

2.3 METHODS OF ARTIFICIAL RECHARGE

A number of methods can be used to recharge water intentionally into aquifers with respect to different local conditions.

2.3.1 Direct Surface Methods

Infiltration Ponds and Basins

This method allows water to infiltrate towards the aquifer by diverting surface flows. Area available for basins and the infiltration rate controls the amount of water to be recharged (Gale *et al*., 2005).

Soil Aquifer Treatment (SAT)

Treated sewage effluent is allowed to infiltrate through infiltration ponds in order to remove pathogens and nutrients. In this method both soil and aquifer are considered as natural filters (Drewes *et al*., 2006).

Recharge Releases

Dams on ephemeral streams are used to retain flood water in the upstream, and slowly release water into the stream bed and then to infiltrate into underlying aquifers, thereby augmenting recharge (Dillon *et al*., 2009).

Ditches and Furrows

For obtaining maximum water contact area for recharge water, ditches and furrows should be arranged closely in areas having irregular topography. (Bhattacharya, 2010).

2.3.2 Direct Subsurface Methods

Recharge Wells

Abandoned bore wells or dug wells in alluvial soil or hard rock areas can be used as recharge wells by gravity flow, when enough source water is available. Diameter of the wells may ranges from 2 to 5 m and depth will be up to 20 m. Recharge water may be diverted through a filter media to avoid clogging of the well and guided through a pipe to the bottom of the well to eliminate the scouring of the well bottom (CGWB, 2000).

Aquifer Storage and Recovery (ASR)

This is the technique for injecting water into a well for storing and retrieval of the water from the same well. It is helpful in aquifers with saline water, where storage is the essential criteria and water treatment is a lesser thought. Recharge of even one-fourth of extracted water may bring a significant increment in recharge (Schaeffer *et al*., 2001) as it ensures little loss by evaporation (Bouwer, 2002).

Aquifer Storage, Transfer and Recovery (ASTR)

This is the method of injecting water into a well for storage, and recovery from another well. This is used to provide additional water treatment in the aquifer by giving extra residence time in the aquifer beyond that of a single well (Dillon *et al*., 2009).

Injection Wells

Injection wells are similar to recharge wells used for augmenting recharge of confined aquifer by pumping in water under pressure. Usually bore holes of 20 cm diameter should be inserted 2 to 3 m below water table. Proper filtration mechanism should be provided at the top. Effectiveness of injection wells depend on,

- Pumping rate
- Permeability of aquifer
- Normal groundwater gradient

Recharge Shafts

When a shallow aquifer is located below impermeable surface, this method can be adopted. Shaft should be 0.5 to 3 m in diameter and depth should be within 10 to 15 m. The shaft should be drilled up to an impermeable stratum. For filtration of recharge water, gravel, pebble, coarse sand should be packed within the shaft. Up to 1 to 2 m in the top, brick work can be carried out for the stability of the shaft (Dillon *et al*., 2009).

Recharge Pits

This method can be adopted where permeable strata is present at shallow depth. Recharge pit of any cross-section is excavated generally 1-2 m wide and 2-3 m deep. The pit should be filled with stones, gravel and sand materials for filtration of source water (CAMTECH, 2010).

Recharge Trenches

In this, trenches of 0.5-1.0 m width, 1-1.5 m depth and 10-20 m length can be constructed. Trenches should be filled with gravel and sand for cleaning of recharge water. This method can be used to recharge a shallow permeable aquifer.

2.3.3 Indirect Methods

Aquifer Modifications

This technique modifies the aquifer parameters to increase the capacity to store and transmit water. With such alterations, the aquifer becomes capable of achieving more natural as well as artificial recharge. Such techniques include,

a. Bore blasting

b. Hydro-fracturing

Induced Recharge

It is also an indirect method of artificial recharge by pumping water from a well, which is hydraulically linked with any surface water sources to induce recharge to the ground water reservoir (Yadav *et al.*, 2012).

2.4 SOURCES OF WATER FOR RECHARGE

Surface water, storm water and reclaimed water are the abundant sources of recharge. In order to ensure the effectiveness of artificial groundwater recharge in water quality aspect it is important to understand the source water quality, the impacts of human activities and the geochemical processes involved like waste disposal, agricultural irrigation and urbanization, groundwater abstraction, salt water intrusion and chemical composition of the rocks etc.

2.4.1 Surface Water

Surface water is the major source of recharge. If it is not polluted or free from all suspended matters it can be directly diverted to the recharge structure. But polluted water from rivers and lakes should go through certain pre-treatment process for purification prior to recharge.

2.4.2 Storm Water Runoff

Due to the variability in quality aspects of stormwater runoff, greater care should be taken before executing the recharge process. Good quality water from rooftops can be directly diverted to dug wells or bore wells. If the contaminated water from industrial runoff, animal wastes, decaying vegetation, and chemicals applied to agricultural lands, septic tank seepage and litter etc. are used for direct recharge, in order to accommodate the soil infiltration effect, treatments like sand filtration is prescribed before recharge.

2.4.3 Potable Water

In arid regions, especially in gulf countries, fresh water coming out of desalination plants is used to recharge aquifer. Due to the high quality of this treated water, chemical and physical properties of aquifer are not altered (Gale *et al.*, 2006).

2.5 RISK FACTORS ASSOCIATED WITH ARTIFICIAL RECHARGE

For any artificial recharge projects the common problems identified are quality of the source water going to be recharged and clogging of the constructed structure during recharge process. In order to avoid these difficulties greater care should be taken in these areas to eliminate human and environmental health problems.

2.5.1 Quality of the Source Water

Quality of water used for recharge is an important criterion of artificial recharge of aquifers. In fact, addition of treated water will improve the water quality of the concerned wells through dilution or treatment (Gale *et al*., 2002).

Groundwater assumes a crucial part in moulding the financial and social well being of many urban areas (Patel *et al*., 2014). The people living in urban areas depend on groundwater for drinking as it is one of the solid and clean well source of water. Deteriation of water quality in urban India has regularly been recognized due to the transfer of sewage and mechanical effluents into surface water bodies (Srikanth, 2009).

Physical, chemical and bacteriological quality of the raw water that is available for the recharge should be analysed substantially to ensure that the quality parameters lie within the permitted limit. According to Todd (1980) desired limits of different water quality parameters are shown in Table 2.1.

Table 2.1 Desired limits of water quality parameters

Parameter	Best results required
Suspended solids	< 1 mg/l
Phosphate	< 1 mg/l
Iron	< 0.5 mg/l
Turbidity	< 0.3 turbidity units

But according to IS: 10500-2012**,** desired limits of different water quality parameters are shown in Table 2.2.

Table 2.2 Desired limits of water quality parameters by IS: 10500-2012

Parameter	Unit	Acceptable limit	Permissible limit
pH		6.5 to 8.5	6.5 to 8.5
TDS	mg/l	500	2000
Turbidity	NTU	1	5
Alkalinity	mg/l	200	600
Total hardness	mg/l	200	600
Calcium	mg/l	75	200

Magnesium	mg/l	30	100
Chloride	mg/l	250	1000
Fluoride	mg/l	1	1.5
Iron	mg/l	0.3	0.3
Nitrate	mg/l	45	100
Sulphate	mg/l	200	400

2.5.2 Clogging of the Recharge Structure

In order to avoid clogging of the well and to ensure that silt free water is recharged into the aquifer, a filtering unit should be combined with constructed recharge structures. Efficient performance of the filtration unit is essential to get maximum benefits from the installed recharge structures.

Roughing filters are utilized essentially as pre-treatment for filter arrangements that will most likely be unable to handle high turbidity or suspended solids in the wastewater source. Roughing filters are for the most part used to separate fine solids from the water that are just somewhat or not held at all by stilling tank or sedimentation tanks, that don't promptly settle. Roughing filtration gives better treatment than fundamental sedimentation strategies and speaks as a better option to all the more costlier coagulation techniques (Wegelin, 1996)

Horizontal Roughing Filter (HRF)

Roughing filters mainly performs as physical filters and it will reduce the suspended solid content in the water. If at all large filter surface area is exposed for filtration, relatively small filtration rate is supported and less chemical and biological processes also.

Wegilin *et al.* (1991) reported that in the past, however, slow-sand-filter operation was often hampered by inadequately pre-treated turbid surface water.

Over the last decade, roughing filtration was rediscovered and is now used for its simple and efficient process. Horizontal-flow roughing filtration received special attention due to its simplicity in construction and reliability in operation. Horizontal-flow roughing and slow sand filters are characterized by their high process stability, ease of operation and remarkable efficiency.

Method for evaluating the efficiency of the filter is based on the filtration theory proposed by Wegelin (1996). When a particle in the water moves through the gravel bed, it is possible to escape the solid particles either on the left or the right side or has a chance to settle at the surface of the gravel.

Hatt *et al.* (2008) reported that increased detention time as a result of clogging did not enhance pollutant removal efficiency.

Horizontal filters have flow in horizontal direction. Unlimited filter length and simple layout are the main advantage of this unit. Flow regulating structures should be installed at the inlet and outlet sections to keep a desired water depth and flow along the filter and to establish an even flow distribution along and across the filter. Filter bed can be divided into three or four compartments and filter medium should be in series as starting with the coarsest to the finest materials, in the flow direction. The effect of surface porosity and roughness of filter media on the performance of particle removal in roughing filtration was noticed as insignificant compared to the size and shape of macro pores in the filter (Ochieng *et. al*., 2006).

Patil *et al.* (2012) reported that HRF can be used effectively to treat different types of wastewater and is designed in such way to get benefit of the removal of particle by sedimentation and filtration. Horizontal roughing filtration is an alternative for supplying drinking water treatment. Highest percentage removal was observed for the filtration velocities less than 1.5 m/h for colour and turbidity removal. Colour removal is poor and in certain circumstances it needs a large area for effective handling.

Samuel *et al*. (2012) developed a multimedia horizontal filter and tested it for pollutant removal efficiency. Gravel, sand and coconut fibre were selected as the media. The hydraulic efficiency of the filter showed a decreasing rate as the sediment level in inflow increased. The filter showed 100 per cent sediment removal in lesser sediment concentrations in inflow water. The filter could remove NO^{3-}, SO_4^{2-} and total solids (TS) effectively. Removal percentages of Mg^{2+} and Na^+ were also found to be good.

Filter Media Size

The use of various grades of filter media in a roughing filter helps the permeation of particles throughout the filter bed and takes advantage of the large storage space offered by larger media and greater removal efficiencies offered by small media. The size of filter media should be arranged decreasingly in the direction of water flow and the uniformity of filter media components should be higher to increase the filter pore space and helps in filter cleaning (Boller, 1993).

Rooklidge *et al.* (2002) evaluated the removal efficiencies of calcite limestone, basaltic river rock, and limestone-amended basalt filter media in horizontal roughing filters and reported that efficiency was marginally improved by 7 per cent for calcite amended basalt filters compared to unaltered filters.

Alternative Filter Media

The filter materials should have enough surface area to facilitate the sedimentation process in the roughing filter and better porosity value to allow the accumulation of the detached particles.

Ochieng *et al*. (2006) proposed that wherever natural gravel is not easily available for filtration, broken brick pieces and improved agricultural waste (charcoal) can be effectively used as pre-treatment media. He observed that charcoal and brick pieces are performing superior than gravel. This result could have the reason that both charcoal and brick pieces have higher surface area and porosity to improve the sedimentation and other filtration mechanisms over gravel medium.

Filtration Rate

Because of the low filtration rates, particles will be gravitationally hold on the surface of the media (Hatva, 1988).

Hendricks (1991) proposed that common filtration rate of horizontal roughing filters is between 0.3 and 1.5 m/h.

Filtration rate likewise impacts the treatment removal. Higher removal in roughing filters is achieved with low filtration rate (Boller, 1993).

(Dastanaie, 2007) stated that horizontal flow roughing filter is equipped for expelling metals like iron, manganese, turbidity and colour at a filtration rate of 1.8 m/h.

Filter Length

Enhanced cumulative removal efficiencies are normally associated with longer filter lengths (Wegelin, 1986). Be that as it may, incremental removal efficiencies tend to diminish with larger channel length because of the special removal of bigger particles initially in the channel (Wegelin, 1996). The rate of decline is reliant on filter design variables and the size and nature of particles in suspension. The use of different media sizes in shorter lengths may allow the treatments to achieve better results compared to long filter packed with one media size.

Jayalath (2004) worked in a pilot HRF plant in Sri Lanka and discovered that there is an impressive diminishment in Synedra populace (80–87% regarding cell count) and colour turbidity (50–60%). Most noteworthy rate of removal was acquired in the structure with filtration rates below 1.5 m/h for colour and turbidity. Field-scale tests demonstrate that channel length does not give a huge impact on the rate of diminishment of colour, algae count and turbidity. He accomplished 85 and 90 per cent individually on iron and manganese removal in the plant.

A HRF was constructed and run by Tamar Rachelle in Northern region Ghana using three 7 m pipes packed with three sizes of granite gravel, local gravel and cracked pieces of ceramic filters arranged by decreasing size. The experiment was run for 52 days to check if HRF could reduce the high turbidity (305 NTU) to < 50 NTU. There were a number of promising results: the best performing media, the granite gravel, by removing an average 46 per cent of the inflow turbidity, made an average effluent turbidity of 51 NTU which almost accomplished the goal of < 50 NTU. The granite gravel, HRF removed doubles as much turbidity (46%) as plain settling (25%). Overall, the granite gravel removed 76 and 84 per cent of the influent turbidity as indicated by the settling test and pilot HRF data respectively (Nkwonta *et al.*, 2009).

Vertical Roughing Filter

In vertical filters, wastewater is applied to the surface of the filter and then drains vertically down through the filter medium towards the bottom. The height of a vertical filter bed is limited to 1.0-2.0 m (Patil *et al.*, 2012).

Satyendra *et al.* (2014) evaluated the performance of two recharge filters having flow patterns in vertical and horizontal directions at CSSRI, Karnal. The results revealed that performance of recharge filter can be improved by arranging filter material horizontally but larger surface area will be required in horizontal filters as compared to vertical to obtain desired filtration rate.

2.6 ADVANTAGES OF ARTIFICIAL RECHARGE

Artificial recharge has a number of possible advantages in which some are listed below.

• It does not require large storage structures to store water. Structures required will be small and cost-effective.

• Enhance the groundwater quantity and yield of wells.

• Compared to surface storage structures, it has negligible losses.

• It will improve groundwater quality due to dilution of dangerous chemicals/ salts.

• Dislocation of local population is not required.

• Due to rise in groundwater table, cost of energy for lifting water will be reducing.

• Make use of the excess surface runoff which otherwise simply drains off.

• The technology is simple and easily well understood by both the experts and the common populace (Dillion *et al.*, 2005).

Ravichandran *et al.* (2011) reported that in order to develop the ground water condition, it is necessary to artificially recharge the exhausted ground water aquifers. In his study, selective techniques of assessing artificial ground water recharge were defined which can be adopted to enhance the ground water recharge. The techniques are easy, economical and viable in the long term. Many of these can be implemented by the individuals, rural and urban communities with locally accessible materials and human power. Even though ground water recharge scheme either naturally or artificially will not be the last answer, but they can contribute for the management of groundwater sustainably by community effort.

2.7 ARTIFICIAL RECHARGE EXPERIMENTS

Taneja *et al.* (1996) conducted recharge studies by injection into a cavity well using artificially prepared turbid water of varying concentrations in a sand tank model. He concluded that it was possible to continue recharge with turbid water at a fixed hydraulic head but the rate of recharge kept on decreasing with time.

Raheja *et al.* (2003) found that due to recharge with sediment laden water, the rise of head increased with increase in recharge time and concentration of recharge water. The recharge rate varied between 1.5 lps to 1 lps during each treatment. The discharge of the well reduced to 50 per cent after 487, 379 and 301 hours of recharge for 50, 100 and 200 ppm recharge water concentration. She thus concluded that technique of recharging with sediment laden water was not suitable as it would reduce the life of the tube well significantly.

Kaledhonkar *et al.* (2002) concentrated on simulated groundwater recharge through recharge tube wells in the North-East Haryana. Two recharge tube wells were introduced in the bed of old Sirsa branch channel to boost the depleted aquifers by artificial recharge. The area and depth of installation of the tube wells were chosen after conducting the resistivity survey in the area. Filtration unit was provided for keeping the recharge water devoid of impurities. The recharge tube wells performed well during whole experiment period covering two rainstorm seasons with no decline in the recharge rate. A normal recharge rate 10.5 lps because of individual tube well was watched, which was sensibly great.

Dahiwalker *et al.* (2007) designed and developed a sand and gravel filter for artificial groundwater recharge at the Groundwater Project, MPKV, Rahuri during 2004-05. Various locally obtainable filter materials like sand, gravel and coal were tested individually and in mixture of two, three and four layers with changing layer width 15, 30 and 45 cm respectively. Influence of filter material on filtration was analysed by noting the inlet and outlet flow, flow velocity, filtration time and efficiency of filtration. In different suspended concentrations, supreme filtration efficiency (79.06) was witnessed for sand grade 45 cm width with normal velocity of flow, 1.91 cm/s. The two layer filter with sand grade 1cm width and coal layer of 15 cm width has produced greater filtration efficiency (81.62%). The three layer filter with 40 cm width of each layer joined with coal grade 15 cm width has produced higher filtration efficiency (83.42%). The filter with four layers given the highest filtration efficiency (97.21%). From the study, it was concluded that the filter with four layers was found superior among all other multilayer filters.

Gorantiwar *et al.* (2007) conducted a recharge study of a percolation tank having its maximum storage capacity 52.5 ha-m at Shingave village located on the out skirts of the campus of the university since 1992-93. Fluctuations of the water level in the pond and selected wells located at downstream side of tank were noted down periodically. Evaporation and rainfall data also were recorded. It was observed that the tendency of deviation of water in the percolation tank is related to the tendency of deviation of water levels in every well in observation. Generally it was observed that the water level in the percolation tank increased from the month of June to December (rainy season) and again dropped from December to June. Similar trend was observed for the water level in the wells with little lag of some time period. It indicated that the water levels in the wells were influenced by the storage of water in the tank. The groundwater recharge as a result of construction of the percolation tank was worked out taking into consideration all the components of flood routing. It was observed from the average recharge over the period of 13 years (1993-2004) that recharge is approximately 86 per cent of the total inflow into the tank and the recharge rate is 2.3 cm/d of the average water spread area of the tank. These facts indicate the percolation tanks are suitable means of recharging of groundwater in hard rock region.

Kar *et al.* (2007) reported that in spite of copious rainfall, complex geology and hydrogeology are mainly responsible for the formation of un-ubiquitous potential groundwater reservoirs Andaman and Nicobar Islands. Thus development of groundwater as also its management in island situation has been a perennial problem in the archipelago. The research and development works have revealed good prospect of development of groundwater through artificial recharge and conservation, watershed development through conjunctive water use and rain water harvesting.

Parmar *et al.* (2007) conducted a study in the instruction farm of College of Agricultural Engineering and Technology, Gujarat Agricultural University. Four numbers of water harvesting structures were constructed, out of which three were drop spillway type having catchment area of 80 to 110 ha and storage capacities of 10200 m^3, 5040 m^3 and 7875 m^3 at site l, ll and lll respectively. At site IV a drop inlet type spillway was constructed having catchment area 90 ha and storage capacity of 4375 m^3. During the year of 2002, dams at sites I and II were filled up for three times and dams at III and IV filled up twice. Due to the construction of water harvesting structures additional 10.2 ha area was brought under cultivation during kharif season. While 10.5 ha area was under irrigation during the rabi season and 8 ha area was under cultivation during summer. Total 28.7 ha area was brought under crop production. Out of 28.7 ha area 17.05 ha area was planted under varied horticulture crops There was increase in groundwater level by 1.14 m in four years. The total groundwater potential in the year 1997-98 was 2, 04, 368 m^3, while in the year 2001-02 it was 2, 87, 068 m^3. Additional groundwater potential was 82,300 m^3.

A study of groundwater recharge was undertaken by Selvi *et al.* (2007) in Salaiyur water shed belonging to hard rock area of Coimbatore district in the state of Tamil Nadu, India, which is fast progressing from grey to black zone in terms of groundwater status. In this water shed comprising about 500 ha, soil and water harvesting works had been carried out under Integrated Watershed Development programme (IWDP) during 1997-2003. In the succeeding years, continuous monitoring of groundwater table on weekly basis was carried out in 65 observation wells distributed over the entire watershed. Groundwater recharge was computed in terms of net increase/decrease in depth to the water table using surfer 8.0 software. Based on water table contours of pre and post monsoon period, it was found that there was a decrease of 0.558 m in depth to the water table for the entire watershed which can be attributed solely to natural groundwater recharge. However, in the year 2005, a total of 861.8 mm rainfall was received leading to the filling of 13 ponds during late august and mid-October. A comparison of two water table contour maps the first drawn prior to the pond filling and the second drawn when the water table in majority of wells had reached the highest showed that increase in the groundwater can be attributed to the positive influence of water harvesting structures present in the watershed in addition to the natural groundwater recharge.

Silva (2007) conducted a study in the drought prone areas of Sri Lanka. As the annual rain fall is not adequate and equally distributed more than 6 months of the year do not receive any rain fall. Groundwater too is limited in the study area and the wells get dried during the drier months. This study was focussed on the possibility of raising the groundwater levels by storing water in open dug wells (pathahas), specialised runoff collection tank and existing village tank (wawe) and an Indian artificial recharging structure during the rainy season in vicinity of the wells. The study results have shown a significant response to the water levels in the well in the vicinity. The contribution to the wells of shallow depth were prominent than the deep wells. All the wells in the study area except the deeper wells were maintained at the average water depth below groundwater level of 4 m which is desirable for year around cultivation.

Sayana *et al.* (2010) reported that the recharge structures constructed in the St Peter's Engineering College Campus has been active in recharging the rooftop water collected and diverted to the percolation pond in the study area as well as the recharge wells in the campus. For duration of four years, the recharge was very effective and it helped to increase the level of the water table in the location and also some ground water flow also appeared towards the downstream.

2.8 CASE STUDIES OF ARTIFICIAL RECHARGE IN KERALA

Sub-surface dykes are basically groundwater conservation structures and are effective to provide sustainability to groundwater structures by obstructing the sub surface flow. A groundwater dam is a sub-surface barrier across the stream which checks the natural groundwater flow of the area and stores water below ground surface to meet the demands during the period of need. The main purpose of groundwater dam is to arrest the flow of groundwater out of the sub basin and increase the storage within the aquifer.

The artificial recharge method like dam, boulder, check and de-silting of tanks, constructions of point recharge structures, gravity recharge and rainwater harvesting structures are studied and applied to the area to get sustainable result in the area. The recharge has benefited the deeper fractured aquifer to build up storage to improve the groundwater table to the tune of 5-10 m and resulted in an improvement in the productivity of the irrigation bore wells (Kumar *et al*., 2007).

Kurien (2007) reported that in many high demand areas, rate of extraction of groundwater has exceeded the rate of natural recharge. This has led to continuous decline in groundwater level and depletion of aquifers. If the current trend of ‘groundwater mining’ continues, the already depleted aquifers are not likely to last long. In such an event when population has over raced the available water resources and food supply, groundwater has become a vulnerable resource. The emerging scenario of groundwater droughts is therefore the main issue of concern. The remedy lies in regulating groundwater withdrawals and recharging the depleted aquifers utilizing the available surplus flow from rainfall and run-off through various artificial recharge methods. Groundwater dams are one of the effective structures in this direction.

Suseela (2007) conducted a study at RARS, Pattambi. The station is situated very near to Bharathapuzha river and is having an area of 61.5 ha with 2/3 $^{rd.}$ of the area as rice field. In spite of all these factors, water had become scarce commodity in the station and nearby villages, which are lying along the course of river. During the rainy season, water table rises and the entire rice field get flooded up to a depth 20 to 30 cm above ground level and gradually recede after the cessation of rainfall. Most of the water stored in the soil escape to the lower portion of the valley and from there to the river. So in order to reduce water scarcity problem of the station, a subsurface dam was constructed across the rice field. During the summer season, the mean static water level in the observation wells and open wells at the upstream side of the dam was 30 to 60 cm above than in the downstream side which helped to reduce the water scarcity problem of the station to some extent.

Suseela *et al*. (2007) conducted a study on the performance evaluation of groundwater recharge system of the farm in a percolation pond which was constructed near the C&B College, KAU, Vellanikkara as a part of the plan scheme. Two observation wells were constructed both on the upstream and downstream side of the pond. The weakly water level observations both in the observation wells and open wells lying on the upstream and downstream side of the pond revealed that percolation pond has greater role in increasing the yield of well and the influence of percolation pond in increasing the yield of wells varies with the distance of well from the pond.

A sub surface dyke at Sadanandapuram was constructed in the valley of the Agricultural University site in the year 1998. The structure constructed was a plastered brickwalls over massive basement and it was kept 1.0 m below groundwater to avoid water togging in the upstream side of the dyke. Three sets of piezometers were constructed on either side of the dyke for water level measurement. Impact assessment study revealed that during the month of May a rise of 0.22 to 0.88 m water level between upstream and downstream side (Saritha, 2010).

A feasibility study of sub-surface dyke for tapping ground water was undertaken at the Aromatic and Medicinal Plants Research station at Odakkali owned by the Kerala Agricultural University under Swedish International Development agency. The dyke was 75 m long and constructed with brick masonry. Polythene sheet was used at the upstream side of the dyke for testing it as cheaper material to the costly brick material and to augment the impermeability of the dyke. While observing the static water level and drawdown of the wells in the upstream and downstream, plastic sheet gave promising results in preventing the leakage. The harvested water is being utilised for drip irrigation. The fact that no water was available for irrigation at the site before construction of the dyke and it indicates the suitability of this system for conserving ground water especially in Kerala (Visalakshi and Abraham, 2005).

A subsurface dyke at Mampazhakkara was situated in Perumpazhathur village of Trivandrum district. It has 63 m length, 23 cm width and 4 to 6 m height. Because of the irrigation potential created by the dyke, the yield of the existing crops especially coconut trees was increased by 80 per cent. A percolation tank was situated at Chirakulam, Uzhavur block, Kottayam district. Dug wells located in the area were getting dry during summer months and the villagers of this area were facing acute shortage of water for all their needs. The structure is constructed in the first order stream, which drains the rain water of the area to the Meenachil river as surface runoff (Saritha, 2010).

CHAPTER-3

Material and Methods

CHAPTER III

MATERIALS AND METHODS

Managed aquifer recharge through tube wells is recommended for directly feeding depleted aquifers by diverting the surface runoff into it. The diverted runoff should be free from suspended and dissolved impurities. In order to ensure this, proper filtration mechanism should be provided. Recharging through this technique is fast and has no inherent evaporation losses. The groundwater table can be improved significantly by this method.

The present study focuses on the design and evaluation of a horizontal filter unit for groundwater recharge through an abandoned tube well located in the research field of the Nodal Water Technology Centre under the Department of Agricultural Engineering, College of Horticulture (CoH), Vellanikkara. The materials used and methods adopted to fulfil the objectives of the study have been enumerated in this chapter.

3.1 DETAILS OF THE STUDY AREA

The experimental site geographically lies between 10º 33’ 3” N latitude and 76º 17’ 2.9 “E. The site is 5 m above mean sea level. In the campus, the surface water resources are utilized fully and usually get dried in summer seasons. Hence to meet the irrigation water needs it is essential to depend on alternate sources like groundwater. In the study area, the tube well 100 m deep dug by the Ground Water Department remains abandoned due to lack of yield.

3.2 CLIMATE

The study area has four distinct seasons, south west monsoon from June to September, north east monsoon from October to December, the winter season from January to February and summer from March to May. The average annual rainfall of the region is 2795 mm which is less than the state average of 3000 mm.

3.3 BASIC PHYSICAL PROPERTIES OF SOIL OF THE STUDY AREA

3.3.1 Infiltration Characteristics of the Soil

Infiltration measurements in the experimental site were done by using double ring infiltrometer. The cylinders 25 cm height and made up of rolled steel were used. Inner cylinder had 30 cm diameter and the outer buffer ring had 60 cm. Cylinders were driven into the soil up to 10 cm depth by using hammer. Water was added to the both cylinders to about three-fourths of the desired level from a container of known volume. Initial water level reading was taken from the inner cylinder by using a hook gauge. Depth of infiltration was noted for constant time intervals. Water was added to the initial level after taking measurements. The experiment was continued till the steady state infiltration rate was achieved.

Plate 3.1 Determination of infiltration rate

3.3.2 Soil Texture

The standard grain size analysis test defines the relative proportions of different sizes of particles in the soil. Texture is an important soil characteristic since it affects the infiltration rate, water holding capacity of the soil and the amount of aeration.

The soil sample was collected from the experimental field by using an auger. The sample was oven dried and subjected to standard particle size analysis through a set of IS sieves of size 4.75 mm, 2 mm, 1 mm, 600 micron, 425 micron, 300 micron, 212 micron, 150 micron and 75 micron. The percentage finer was calculated on the basis of percentage of soil retained in each sieve. Particle size v/s percentage finer relationship was analysed and the texture was identified.

3.3.3 Permeability of the Soil

Permeability is the ability of a medium to transmit water and the coefficient of permeability is proportional to the square of average particle size in a soil. Coefficient of permeability was determined by constant head permeameter method.

Undisturbed soil sample was collected from the field. After saturating the sample in a tray of water for 1 hour, the sample was filled in a constant head permeameter experimental set up. The water supply was given to constant head permeameter. The soil column length 'L' (cm) and the head of the water over the soil column, h (cm) were noted. Measuring cylinder was placed below the soil column to collect the discharge. The water was allowed to flow through the soil column and the drained water was measured once in 10 minutes and the process was repeated till the consecutive constant values were reached. The coefficient of permeability was calculated as

$$K = \frac{Q.L}{t.h.a}$$

where

K - Coefficient of permeability (cm/s)

Q - Discharge collected (cm^3)

L - Soil column length (cm)

h - Head of the water over the soil column (cm)

t - Time (sec)

a – Cross sectional area of soil column (cm^2)

3.4 GEOLOGY OF THE AREA

Characteristics of the geological formations of the area was identified by using the Vertical Electrical Sounding experiment data obtained from the Groundwater Department, Thrissur and the data was recorded for drilling the tube well dug by Groundwater Department in the area on 04/10/2013. Data are given in Chapter IV.

3.5 ESTIMATION OF GROUNDWATER RECHARGE

The method of estimation of recharge from rainfall includes the following processes,

3.5.1 Collection of Rainfall Data for the Study Area.

The average annual rainfall data for 16 years (from 2000 to 2015) were collected from the department of meteorology, CoH Vellanikkara, KAU and is presented in the chapter IV.

3.5.2 Determination of Annual Recharge Using Empirical Formulae.

The average annual rainfall data collected was used to estimate the recharge from rainfall by using the following two empirical equations which are calibrated for the southern regions of India.

Kumar and Seethapathi formula

$$RWR = 0.63\ (R - 15.28)^{0.76}$$

where,

RWR = Groundwater recharge from rainfall (inch)

R = Mean rainfall (inch) (Kuruppath, 2015)

Krishna Rao formula

According to Krishna Rao formulae, the rainfall–recharge empirical relationship can be expressed as,

$$GWR = 0.35 (R - 600)$$

where,

RWR and R are Groundwater recharge and rainfall respectively expressed in millimetres. (Kuruppath, 2015)

The calculated values of recharge by two different methods were used to establish a relationship between average annual rainfall and recharge and the results are represented in chapter IV.

3.6 ESTIMATION OF EXPECTED PEAK RUNOFF

Estimation of the peak runoff expected from the area was done using rational formula

$$Q_p = \frac{CIA}{360}$$

where

Q_p = design peak runoff rate (m^3/s)

C = dimensionless runoff coefficient

I = intensity of rain for a duration equal to the time of concentration and (mm/h)

A = area (ha)

Values of runoff coefficient are dependent on vegetative cover, slope and soil texture.

Estimation of the area contributing runoff to the recharge well, length of flow and slope of the watershed was done to calculate the peak flow rate. The value of intensity of rainfall of one hour duration was calculated by the formula

$$I = \frac{KT_r^{\,a}}{(T_c + b)^n}$$

where

I = intensity of rainfall, cm/h

T_r = recurrence interval, yr

T_c = time of concentration, h

K, a, b and n are constants for southern region of India.

Time of concentration (min), $T_c = 0.0195\ L^{0.77}\ S^{-0.385}$

where

L = maximum length of flow (m)

S = average slope of the area (%) (Das, 2010)

3.7 CHANNEL CARRYING CAPACITY

The recharge structure was planned to be constructed in the existing drainage channel of trapezoidal cross section having bottom width 60 cm, side slope 0.5: 1 and depth 50 cm. Channel carrying capacity was calculated using Manning's equation. After analysing the peak rate of runoff in comparison to the channel carrying capacity, the same channel was modified to construct filter unit and recharging unit.

The conveying channel of 10 m length and 60 cm bottom width was modified to divert the surface runoff towards the filter bed collected from nearby area. The channel was lined with UV stabilized polyethylene sheet in order to prevent the channel scouring and weed growth in the channel bed.

3.8 EXPERIMENT SET UP

The experimental set up for evaluating the performance of horizontal filter unit was constructed in the existing conveyance channel (Plate 3.2).

3.8.1 Settling Tank

A settling tank of 75 cm length, 60 cm width and 25 cm depth below the filter bed level was constructed at the inlet of the masonry channel. It will reduce the flow velocity of the runoff approaching the filter bed and the larger particles will get settled down in this chamber.

3.8.2 Filter Unit

A masonry structure with 6.5 m length, 0.60 m width and 0.50 m depth was constructed in the channel. The chamber is partitioned into 5 sections, the length of which can be adjusted by vertical mesh frames (1 cm × 1 cm) (Plate 3.3). The lengths of different filter media can be altered by changing the position of these mesh frames in the respective slots made in the masonry structure. Among the five chambers, four are used to fill different filter materials for conducting performance evaluation studies and the remaining one is used to keep constant flow depth over the V notch placed at the end of the masonry filter bed. Plastic nets having apertures of size 0.5 mm was fitted to the separating frame of the chamber filled with sand to avoid washing of the sand medium and to facilitate filtration. Each chamber was cleaned after every test. A gentle slope of 1 per cent is allowed along the longitudinal direction of the filter bed in order to facilitate the flow through the channel.

3.8.3 Collecting Tank

A masonry structure of 1.95 m length, 1.95 m width and 1 m depth was constructed around the proposed tube well for collecting the outflow from the filter bed.

Plate 3.2 Experimental setup

Plate 3.3 Filter unit

3.8.4 V Notch

A V notch is placed at the end of the filter unit for measuring the outflow rate from the filter. It was constructed using 2 mm gauge mild steel sheet and with standard dimensions. The details are given in Figure 3.1

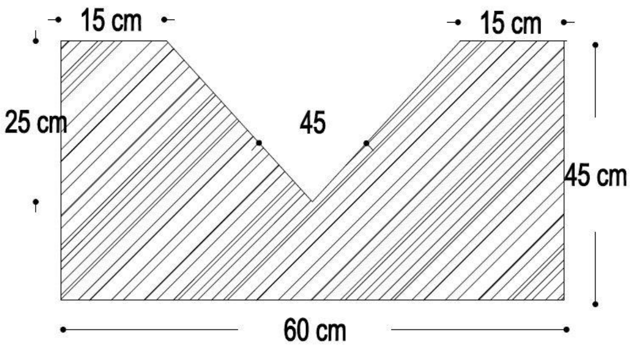

Figure 3.1 V Notch placed in the channel

Roofing was given to the recharge structure to avoid the pollution of filtered water from outside sources. Details of the designed setup are shown in Figure 3.2.

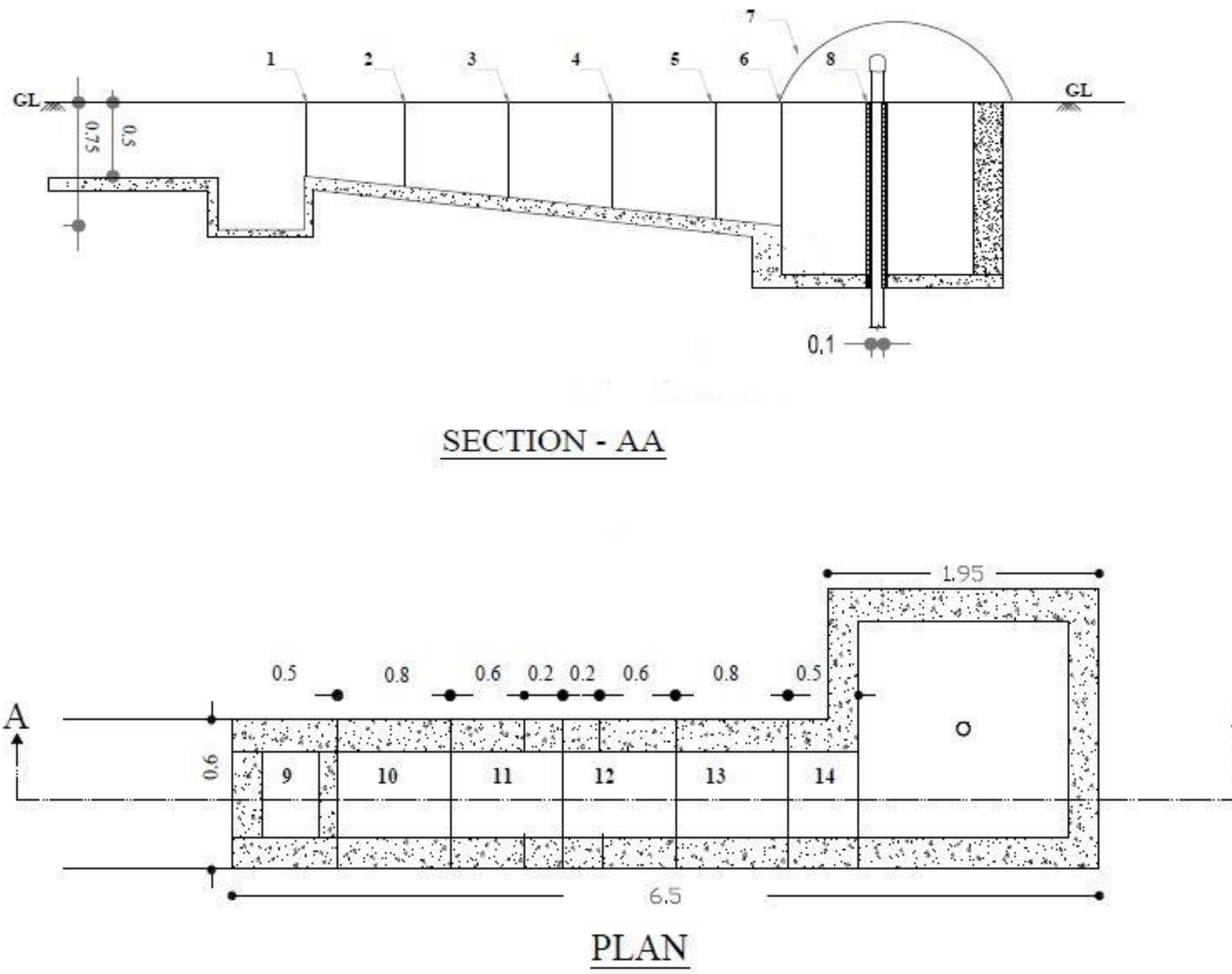

Figure 3.2 Schematic of the experimental setup

1,2,3,4,5: Separations provided 9: Settling tank

6: V notch 10,11,12, and 13: Compartments to fill filter materials

7: Roofing

8: Tube well 14: Collecting tank to get constant head over V notch

3.9 DESIGN OF FILTER MEDIA

Size of the filter materials (Gravel and Sand) were selected according to the standard criteria for design of filter materials as proposed by United States Bureau of Reclamations (USBR). Particle size gradation curves of soil from the experimental site and sand filter media were prepared from the mechanical analysis data. Design of size ranges for gravel media and stability ratio for sand were calculated based on the following equations.

Size ranges of gravel medium:-

$$\frac{d_{50} \text{ of filter materia}}{d_{50} \text{ of site soil}} = 12 \text{ to } 58$$

Stability criteria of sand medium:-

$$\frac{d_{15} \text{ of filter material}}{d_{85} \text{ of the site soil}} < 5$$

where

d_{50} = Size, in mm such that 50 per cent of the particles are finer than this size

d_{15} = Size, in mm such that 15 per cent of the particles are finer than this size

d_{85} = Size, in mm such that 85 per cent of the particles are finer than this size

(Singh *et al.*, 2002)

Based on the standard design criteria, filter media were selected and three treatments were fixed for evaluating the filter performance by changing media combinations. Filter materials should be permeable, easily and commercially available, cheap, environment friendly, more durable, and easy to handle during the experiment. The materials selected were, T1: Gravel, Sand, Coir fibre, Gravel

T2: Gravel, Sand, Synthetic fibre, Gravel

T3: Gravel, Charcoal, Sand, Gravel

Filter media were arranged in the decreasing order of size in the flow direction.

Factors were fixed as varied combinations of lengths of filter media as shown below,

F1: 80 cm, 80 cm, 80 cm, 80 cm

F2: 80 cm, 100 cm, 60 cm, 80 cm

F3: 80 cm, 60 cm, 100 cm, 80 cm

The observations were replicated thrice for each treatment. The details of the experiment design are given in Table 3.1. The major filter materials chosen are shown in Plates 3.4 (A) to 3.4 (C)

Plate 3.4 (A) Coir fibre

Plate 3.4 (B) Synthetic fibre

Plate 3.4 (C) Charcoal

Table 3.1 Experimental design

Treatment	Combinations (in the direction of flow)	Length (m)
T1F1	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	0.8
	Coir fibre	0.8
	Gravel (40 mm)	0.8
T1F2	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	1.0
	Coir fibre	0.6
	Gravel (40 mm)	0.8
T1F3	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	0.6
	Coir fibre	1.0
	Gravel (40 mm)	0.8
T2F1	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	0.8
	Synthetic fibre	0.8
	Gravel (40 mm)	0.8
T2F2	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	1.0
	Synthetic fibre	0.6

	Gravel (40 mm)	0.8
T2F3	Gravel (10-20 mm)	0.8
	Sand (0.6–2 mm)	0.6
	Synthetic fibre	1.0
	Gravel (40 mm)	0.8
T3F1	Gravel (10-20 mm)	0.8
	Charcoal	0.8
	Sand (0.6–2 mm)	0.8
	Gravel (40 mm)	0.8
T3F2	Gravel (10-20 mm)	0.8
	Charcoal	0.6
	Sand (0.6–2 mm)	1.0
	Gravel (40 mm)	0.8
T3F3	Gravel (10-20 mm)	0.8
	Charcoal	1.0
	Sand (0.6–2 mm)	0.6
	Gravel (40 mm)	0.8

Following schematic represents the variation of length for treatment T1 adopted during the study.

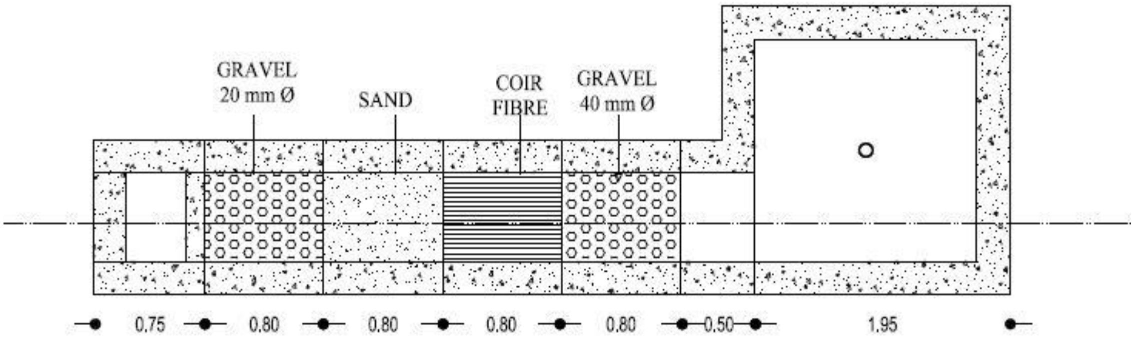

Figure 3.3 (A)

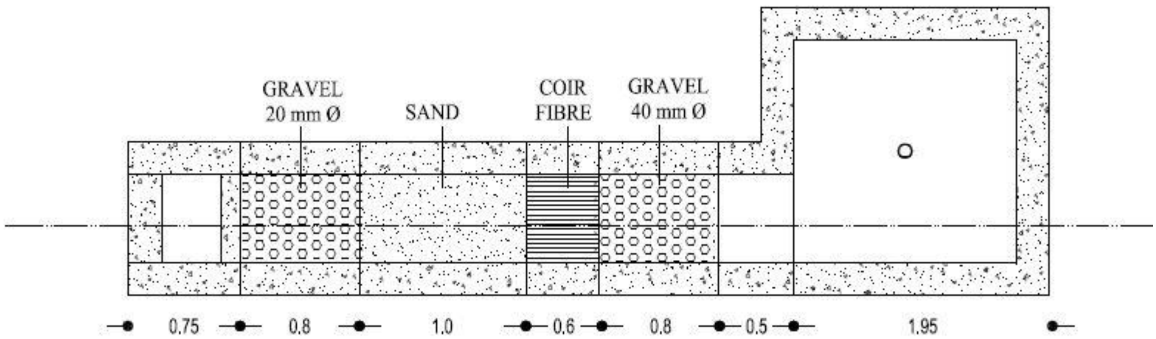

Figure 3.3 (B)

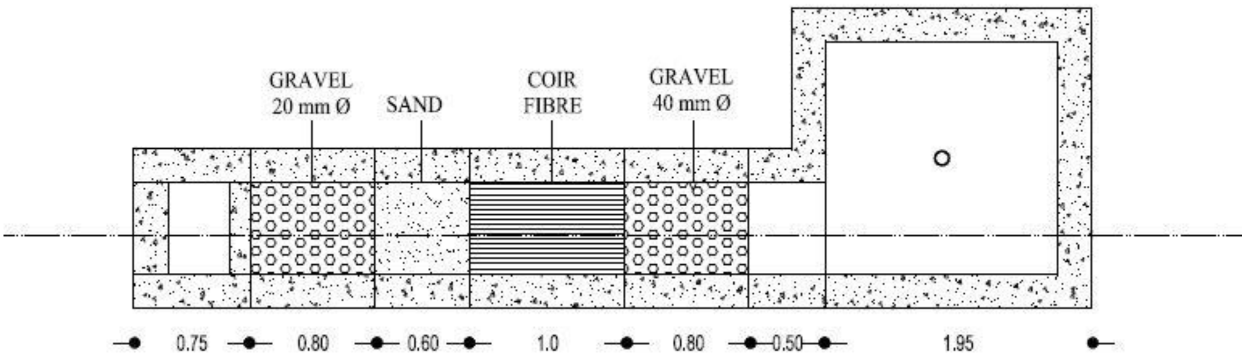

Figure 3.3 (C)

Figure 3.3 Schematic of the T1 experiments

(A) T1F1 (B) T1F2 (C) T1F3

Arrangements of filter materials for varied lengths were repeated also for treatments T2 and T3.

3.10 PERFORMANCE EVALUATION OF FILTER UNIT

Artificial runoff was created in the study area by flooding the surrounded area and the interceptor channel by delivering water from a water tanker and the water source was an open well. The runoff reached the settling tank through the interceptor channel by passing the agricultural field and nearby road. By the force of gravity larger particles settled down in the settling tank and the water flows towards the filter bed. Inflow rate to the filter bed was found by constant volume method. Time taken for filtering the runoff was noted as retention time. Outflow rate from the filter bed was measured by using the V notch placed at the outlet section of the masonry chamber. Inflow and outflow water samples were collected in pre-cleaned polythene bottles with necessary precautions. The water samples were further analysed for physical and chemical parameters.

The experiment was carried out as one media combination with one particular length factor in a day, *ie*; the different treatments were completed in different days in the field itself.

3.11 INFLOW RATE TO THE FILTER BED

Inflow rate to the filter bed was calculated by using the constant volume method by noting down the time taken to fill the settling tank. The flow can be calculated by the formula,

$$\text{Inflow rate (lps)} = \frac{\text{Volume of the settling tank, litres}}{\text{Time taken to fill, seconds}} \qquad \text{(Michael, 2007)}$$

3.12 FILTRATION VELOCITY

Filtration velocity for each treatment was calculated from the retention time noted during the experiment. The retention time was noted as the time taken by water to travel through the filter unit from the inlet to the outlet.

3.13 OUTFLOW RATE FROM THE FILTER BED

For measuring the outflow from the filter bed, a V notch made of 2 mm thick mild steel with 25 cm head was installed at the exit of the masonry structure. By using a steel rule the depth of flow over the notch was measured. Zero of the scale was coinciding with the apex of the V-notch and the smallest division in the scale was 1 mm. Outflow rate was calculated by the equation,

$$Q = 0.0138\ H^{5/2}$$

where, Q = Outflow rate (lps)

H = Head over the apex (cm)

3.14 FLOW VELOCITY THROUGH THE INTERCEPTOR CHANNEL

Flow velocity through the interceptor channel during the actual rainy days was measured by float method. Time taken by the float to travel 6 m distance was noted down.

3.15 ANALYSIS OF PHYSICAL PARAMETERS OF WATER SAMPLES

Physical parameters of the water samples like pH, electrical conductivity (EC), total dissolved solids (TDS), salinity and turbidity etc. were analysed by using the WATER ANALYSER 371 (Plate 3.5) in the laboratory of Nodal Water Technology Centre, Department of Agricultural Engineering, CoH, Vellanikkara.

Plate 3.5 Water Analyser

3.15.1 Specifications of WATER ANALYSER 371

pH

Range	0 to 14.00 pH
Resolution	0.01 pH
Accuracy	± 0.01 pH

For calibrating the analyser for pH measurement, buffer solutions are prepared with pH of 4.0 and 7.0.

Electrical Conductivity and TDS

Range	0.1 µS/cm to 100 mS/cm
	0.1 ppm to 50 ppt
Accuracy	± 1 %
Sensor	Glass Conductivity Cell

For calibrating the instrument to measure EC and TDS, standard KCl solution was prepared. It was done by dissolving 7.459 g of KCl in 1 litre distilled water. This gives 0.1 M KCl solution. Diluting this solution in 1:10 proportion gives 0.01 M KCl solution.

Salinity

Range	0.1 to 40.00 ppt
Resolution	0.1 ppt
Accuracy	± 2 %
Sensor	Glass conductivity cell
	(Acceptable 1.0 ± 10 % cell constant)

Diluting the 10 g of dried NaCl in 1 litre distilled water gives 10 ppt standard solution for salinity measurement.

Turbidity

Range	0 to 100 NTU
Sensor	Silicon photodiode

The standard stock solution of 4000 NTU was prepared by the following procedure.

- Preparation of solution A was done by dissolving 5 g of Hydrazine sulphate in 400 ml of distilled water.
- Preparation of solution B was done by dissolving 50 g of Hexamethelyne Tetramine in 400 ml distilled water.
- Solution A and B were mixed thoroughly and made up to 1 litre and it was kept to settle for 48 hours.
- From this solution calibrating solutions of 1 NTU, 10 NTU and 100 NTU were prepared according to the details shown in Table 3.2

Table 3.2 Preparation of standard stock solution

Volume of stock solution (ml) to make up 1 litre with distilled water (ml)	**Final strength of stock solution (NTU)**
125	500
25	100
12.5	50
20.0 of 500 NTU solution	10
20.0 of 50 NTU solution	1

Those samples for which Turbidity was beyond 100 NTU, measurements were done along with chemical analysis, in Kerala Water Authority laboratory, Thrissur.

Total Suspended Solids (TSS)

Each 1 litre water samples collected were allowed to filter through a filter paper. Solids retained on the paper were weighed after oven drying it. Result obtained was noted as TSS (mg/l).

3.16 CHEMICAL ANALYSIS

Chemical analysis of the water samples collected was done in Kerala Water Authority Laboratory, Kizhakkumpattukara, Thrissur. Concentrations of chemical parameters like Calcium (Ca), Magnesium (Mg), Sulphate (SO_4), Iron (Fe), Chloride (Cl), Fluoride, Total Hardness ($CaCO_3$), Acidity, Alkalinity, and Nitrate (NO_3) were found out by using standard methods.

3.17 STUDIES ON FILTER EFFICIENCIES

3.17.1 Hydraulic Efficiency

Hydraulic efficiency (HE) is the measure of the fraction of the inflow water that passes through the filter. Hydraulic efficiency can be calculated as,

$$HE = \frac{\text{outflow rate}}{\text{inflow rate}} \times 100$$

3.17.2 Pollutant Removal Efficiencies

From the physical and chemical parameters of the inflow and outflow water samples, removal efficiency of each parameter was calculated.

pH normalising efficiency (%)

$$= \frac{pH_i - |7 - pH_o|}{pH_i} \times 100$$

where

pH_i = pH value of the inflow water sample

pH_o = pH value of the outflow water sample

Pollutant Removal efficiencies for other parameters were calculated by the formula,

$$\text{Pollutant removal Efficiencies} = \frac{C_i - C_o}{C_i} \times 100$$

where

C_i = Concentration of the chemical parameter in the inflow water sample

C_o = Concentration of the chemical parameter in the outflow water sample

(Samuel *et al.*, 2012)

Pollutant removal efficiencies for Calcium (Ca), Magnesium (Mg), Sulphate (SO_4), Iron (Fe), Chloride (Cl) , Fluoride, Total Hardness ($CaCO_3$), Acidity, Alkalinity, and Nitrate (NO_3) were found out by this formula.

3.18 STATISTICAL ANALYSIS

Significance of treatments over the hydraulic and pollutant removal efficiencies calculated was analysed using the standard programme of MTS for Factorial Completely Randomised Design (FCRD) with three replication values. Significance of the treatments was ascertained by analysing the probability value (P value) of the test. If P less than 0.05, the treatment is significant at 5 per cent level of significance. Whenever P less than 0.01, the treatment was identified as highly significant *ie*. at 1 per cent level of significance. If P greater than 0.05, then the treatment was considered as not significant. Based on these tests, the significance of one treatment over the other could be ascertained.

3.19 SELECTION OF BEST TREATMENT COMBINATION

In order to select the best treatment combination, Duncan's Multiple Range Test (DMRT) was performed over the hydraulic and pollutant removal efficiencies. Best efficiency value obtained from the ANOVA mean values of the FCRD test, over every filter performance efficiencies was given 'a' rank with a ranking value '1'. Followings were marked with rank 'b', 'c', 'd etc. with rank values '2', '3', '4' etc. Rank values of each treatment were added together and the treatment that obtained the lowest overall rank value was selected as best treatment combination.

3.20 FIELD EVALUATION

Best two treatments were selected based on the lowest rank value and they were again tested in the actual rainy days by diverting the natural runoff towards the filter. Inflow and outflow water samples were collected and tested for physical and chemical parameters. pH normalization efficiency and all other pollutant removal efficiencies were calculated. Based on the results obtained from the two sets of filter testing experiments, the best treatment was selected for installation in the filter unit.

3.21 RECHARGE THROUGH THE TUBE WELL

The selected filter media was installed to recharge through the proposed abandoned tube well, which was cased with 2 mm thick PVC pipe.

To recharge water through this PVC pipe, perforations of size 12 mm were made in the extended pipe of the tube well. Holes were drilled by using battery powered drill bits for an effective length of 50 cm in the bottom portion of the pipe and it is shown in Plates 3.6 (A) and 3.6 (B).

Plate 3.6 (A) Drilling holes in the pipe

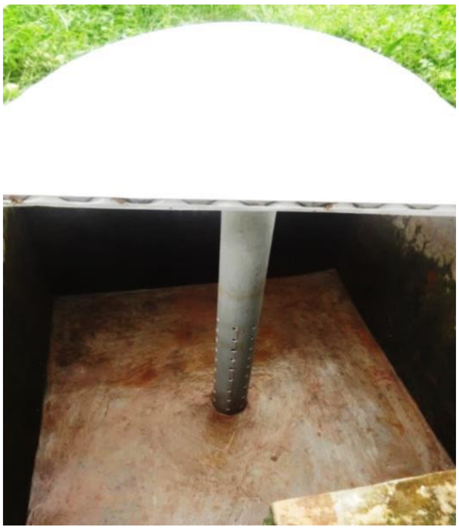

Plate 3.6 (B) View of holes made in the pipe

In order to prevent the entry of fine particles into the tube through these perforations and to improve the quality of the recharging water, the pipe was wrapped with synthetic nylon nets with high durability (Plate 3.7).

Plate 3.7 Pipe wrapped with nylon net

To measure the recharge rate through the tube well, filtered water was allowed to be collected in the sump constructed around the tube well after closing the holes by wrapping the pipe by plastic sheets. After collecting a certain depth of water in the tank, the plastic sheet covering was removed and the time taken for recharge was noted. From this, rate of entry of water to the tube well was calculated. Recharge was continuously observed for consecutive 3 days and no ponding or lagging was observed.

3.22 COST OF INSTALLATION

Cost of installation of the filter unit was calculated including the construction cost of the filter unit, input cost of filter materials and the maintenance cost. The calculations are shown in Chapter IV.

CHAPTER-4

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The study was conducted during December 2015-June 2016 in the research plot of the Nodal Water Technology Centre, CoH, Vellanikkara. The design and evaluation of the horizontal filter unit was done and the performance evaluation of the filter unit for different filter media combinations were performed in terms of hydraulic and pollutant removal efficiencies. Finally recharging of the groundwater through the abandoned tube well after installing the best filter medium combination was done. The results and discussions pertaining to the objectives are presented in this chapter.

4.1 BASIC SOIL PHYSICAL PROPERTIES OF THE STUDY AREA

4.1.1 Infiltration Rate

A double ring cylinder infiltrometer test was conducted to determine the infiltration rate of the soil as the inflow to the filter unit was influenced by the infiltration properties of the soil.

The basic infiltration rate of sandy loam soil ranged between 36-180 cm/h. The average basic infiltration rate of the soil was found to be 56.17 cm/h. Data are given in Appendix I.

4.1.2 Textural Analysis

The soil sample was collected from the experiment location. The soil was lateritic in nature and was analysed for grain size distribution and the procedure is given in section III. The particle size distribution curve plotted for the soil sample is shown in Figure 4.1.

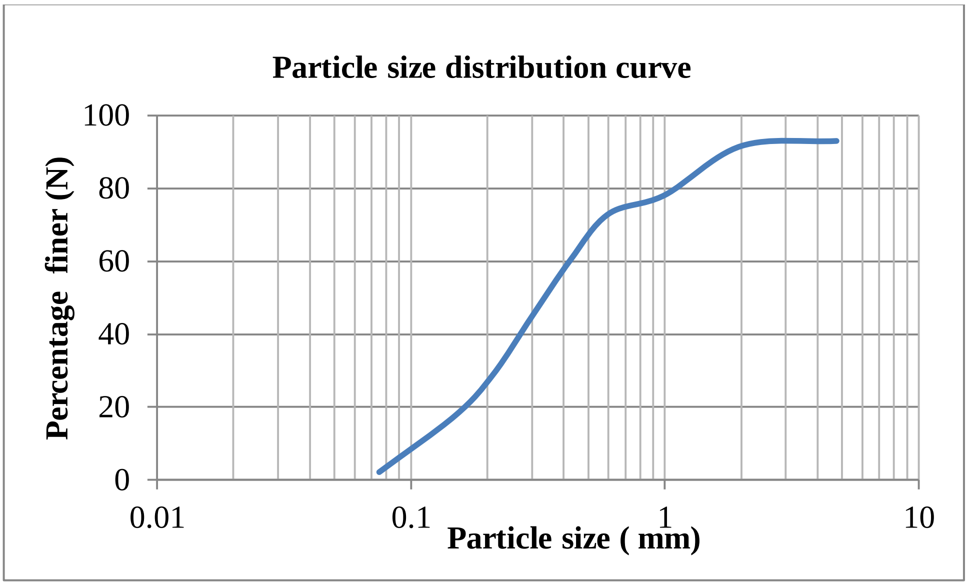

Figure 4.1 Particle size distribution curve of soil

In the curve, percentage finer ‘N’ was taken as ordinate and particle size (mm) as the abscissa on logarithmic scale. The analysis indicated that the soil sample consisted of 77.22 per cent sand of size range 2 to 0.075 mm and 21.4 per cent fine fractions. Major portion of the site soil was found as sandy in texture. Data is provided in Appendix II.

4.1.3 Permeability of the Soil

The subsurface movement of water is greatly influenced by the hydraulic conductivity of soil. The hydraulic conductivity of sandy soil by constant head permeameter method was obtained as 1.74 cm/s. Generally, the hydraulic conductivity of sandy loam lies within the range 1.4 to 4.34 cm/s. Data is given in Appendix III.

4.2 GEOLOGY OF THE AREA

Clear idea about the geology of the formations in the study area was obtained from the vertical electrical resistivity experiment done in the area by Groundwater Department during drilling the tube well. Data on geologic formations are given in Table 4.1.

Table 4.1 Data on geologic formations of the area

Sl No	Depth (m)	Resistivity value (ohm-cm)	Nature of the geologic formations
1	2	483	Most to dry sand and gravel
2	3	472	Most to dry sand and gravel
3	4	407	Most to dry sand and gravel
4	5	341	Most to dry sand and gravel
5	6	277	Clay, Sand and Gravel
6	8	254	Clay, Sand and Gravel
7	10	261	Clay, Sand and Gravel
8	12	278	Clay, Sand and Gravel
9	15	306	Clay, Sand and Gravel
10	20	351	Most to dry sand and gravel
11	25	390	Most to dry sand and gravel
12	30	375	Most to dry sand and gravel
13	35	401	Most to dry sand and gravel
14	40	422	Most to dry sand and gravel
15	45	441	Most to dry sand and gravel
16	50	470	Most to dry sand and gravel
17	60	547	Crystalline rock
18	70	596	Crystalline rock
19	80	582	Crystalline rock
20	100	620	Crystalline rock

From the Table 4.1, it was evident that the formation through which tube is constructed is mostly formed of gravel, sand and clay materials. Up to 5 m depth dry sand and gravel was present. From 5 m to 15 m depth clay, sand and gravel was present. The presence of clay may be the reason for low natural recharge to the subsurface layers due to its low permeable nature of the clay materials and it has been reduced the aquifer yield. But from 15 m to 50 m high drainable materials like dry sand and gravel character was present, so the artificial recharge through this abandoned well will be the better recharge option for this particular area. The continuing formation is crystalline rock up to 100 m depth. There are chances of occurrence of cracks and ruptures in the rock formation which will also contribute to the effectiveness of artificial recharge in the study area. So the area was found as suitable for artificial recharge through the existing tube well in the field.

4.3 RAINFALL-RECHARGE ASSESSMENT

Rainfall is the major source of recharge to groundwater. The amount of recharge from rainfall depends on various hydro-meteorological and topographic factors, soil characteristics and depth to water table. Several empirical formulae are being used to work out rainfall recharge relationship in India on the basis of detailed studies. Among them two empirical equations, which are suited for the southern region of India were selected and the rainfall - recharge relationship of the study area was found out. They are,

1. Krishna Rao formula

2. Kumar and Seethapathi formula

The average annual rainfall data for 16 years (from 2000 to 2015) were collected from the department of meteorology, CoH Vellanikkara, KAU. The data are given in the Figure 4.2 and Appendix IV.

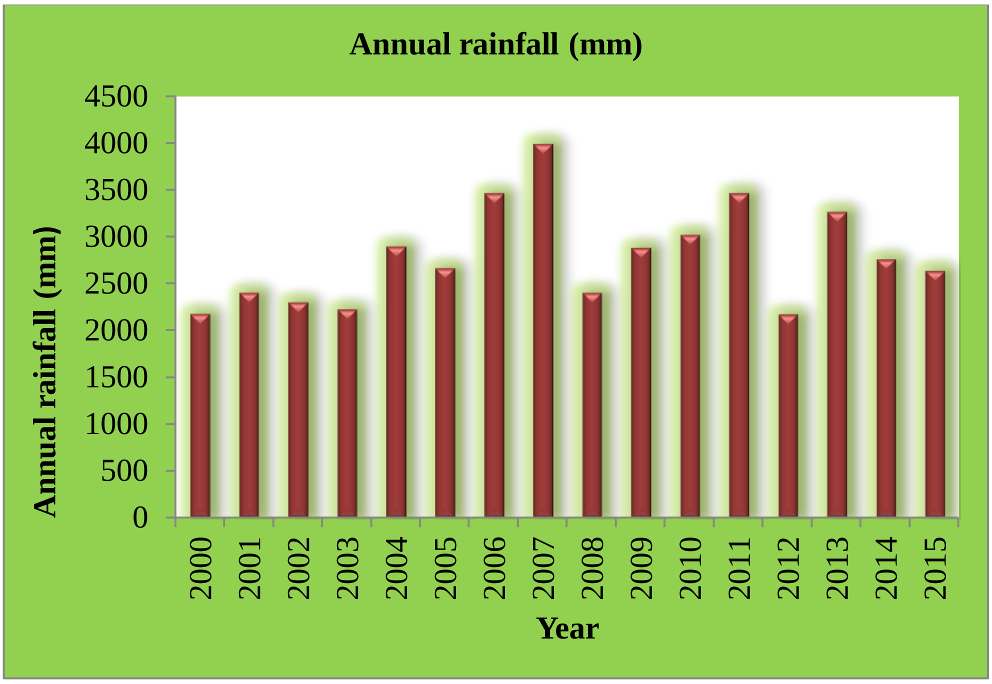

Figure 4.2 Average annual rainfall of the region

A comparison of the annual recharge percentage by the empirical formulae was done for the study area (Table 4.2). It was found that maximum recharge percentage was obtained by using Krishna Rao formula.

According to Kumar formula, the maximum recharge occurred in the year of 2007 as 871.72 mm. The estimated value of recharge percentage by Krishna Rao formula was found highest in the year 2007 as 29.74 per cent.

Table 4.2 Comparison of rainfall - recharge percentages by the empirical formulae

Year	**Rainfall (mm)**	**Annual recharge in percentage (%)**	
		Kumar & Seepathi	**Krishna Rao**
2000	2179	22.62	25.36
2001	2400.1	25.72	26.25
2002	2303.6	24.67	25.88

2003	2223	22.92	25.55
2004	2895.2	23.67	27.74
2005	2663.1	25.452	27.11
2006	3460.5	21.57	28.93
2007	3992.8	21.83	29.74
2008	2403.7	25.61	26.26
2009	2883.3	23.77	27.71
2010	3018.4	22.02	28.04
2011	3465.3	20.96	28.93
2012	2170.4	22.77	25.32
2013	3264.5	22.01	28.56
2014	2756.8	24.11	27.38
2015	2639.4	22.14	27.04
Average recharge (%)		**23.24**	**27.24**

By analysing the average annual recharge it was evident that around 70 per cent of the rainfall occurring in the study area was lost every year as surface runoff. This reflects the abundant volume of source water available for recharging and it should be managed and utilized via artificial recharge method. This can contribute to ample scope for improving the groundwater potential of the area.

4.4 ESTIMATION OF PEAK RUNOFF

The area contributing runoff towards the experimental site was identified in the rainy season. The site was situated near to the road and from one side of the divider runoff was initialized towards the site passing through the agricultural field. The area contributing runoff was estimated as 0.2 ha with 200 m length of flow. Average slope of the area was 3 per cent.

Peak runoff expected from the area contributing towards the recharging unit was estimated by using the rational formula,

$$Qp = \frac{CIA}{360}$$

where

Q_p = Design peak runoff rate (m^3/s)

C = Dimensionless runoff coefficient

I = Intensity of rain for a duration equal to the time of concentration and (mm/h)

A = Area (ha)

C value was taken as 0.3 from standard tables.

Time of concentration, $T_c = 0.01947\ L^{0.77}\ S^{-0.385}$

$= 0.01947\ (200)^{0.77}\ (0.03)^{-0.385}$

$= 4.5$ min

Intensity of rainfall was calculated by using the formula,

$$I = \frac{KT_r^{\,a}}{(T_c + \mathrm{b})^{\mathrm{n}}}$$

where

I = Intensity of rainfall, cm/h

T_c = Recurrence interval, yr

T_r = Time of concentration, h

K, a, b and n are constants for southern region of India. The values are taken as 6.31, 0.153, 0.50 and 0.95 respectively (Das, 2010). Intensity value was obtained as 17.81 cm/h for a recurrence interval of 25 years. Therefore peak runoff was obtained as 0.03 m^3/s.

4.5 CARRYING CAPACITY OF THE CHANNEL

By using manning's equation, channel carrying capacity was calculated as 0.28 m^3/s and velocity of flow through the channel as 0.88 m/s (Wetted area = 0.32 m^2, Hydraulic radius R = 0.21, Channel slope = 1%). Non scouring velocity allowed for sandy loam soil is 5.75 m/s and the maximum velocity of flow observed during rainy days is 0.25 m/s (Table 4.3). Hence the peak flow is not expected to scour the channel bed.

From the peak runoff expected from the area and the channel carrying capacity calculated, it was found that the existing channel was sufficient to carry the peak runoff from the whole area. So the channel as such was selected for developing the filter unit in it. The view of modified channel is shown in Plate 4.1.

Plate 4.1 Filter unit with conveying channel

4.6 FLOW VELOCITY THROUGH CONVEYING CHANNEL

Flow velocity was calculated by using the time taken by the float to travel 6 m in the channel. The data are given in Table 4.3.

Table 4. 3 Runoff velocity through the conveying channel

Runoff Velocity through the conveying channel			
	Distance travelled (m)	**Time taken (sec)**	**Velocity (m/s)**
Day 1	6	24	0.25
Day 2	6	35	0.17
Day 3	6	41	0.14
Day 4	6	39	0.15
Day 5	6	27	0.22
Average			**0.18**

Average velocity of flow was found as 0.18 m/s and the maximum velocity value was 0.25 m/s.

4.7 DESIGN OF FILTER MEDIA

Size range of filter materials (Gravel and sand) was selected based on the design criteria proposed by USBR.

Filter design criteria for gravel:

$$\frac{d_{50} \text{ of filter materia}}{d_{50} \text{ of site soil}} = 12 \text{ to } 58$$ (Singh *et al.*, 2002)

d_{50} of site soil × 12 = 4.2 mm

d_{50} of site soil × 58 = 20.5 mm

Where d_{50} of the site soil obtained from gradation curve was 0.35 mm. Accordingly, size of gravel for filling in the unit was selected as 10 to 20 mm which is between 4.2 mm to 20.5 mm as specified in the design criteria.

Sand filter medium size 0.6 to 2 mm was selected based on the standard size range of filter materials using in slow sand filters. The selected size range of sand was tested for stability criteria.

According to USBR, stability criteria for sand $\frac{d_{15} \text{ of filter material}}{d_{85} \text{ of the site soil}}$ should be less than 5. It was found as 0.83 which is less than the maximum allowed value. Respective particle size distribution curves are shown in Figure 4.3.

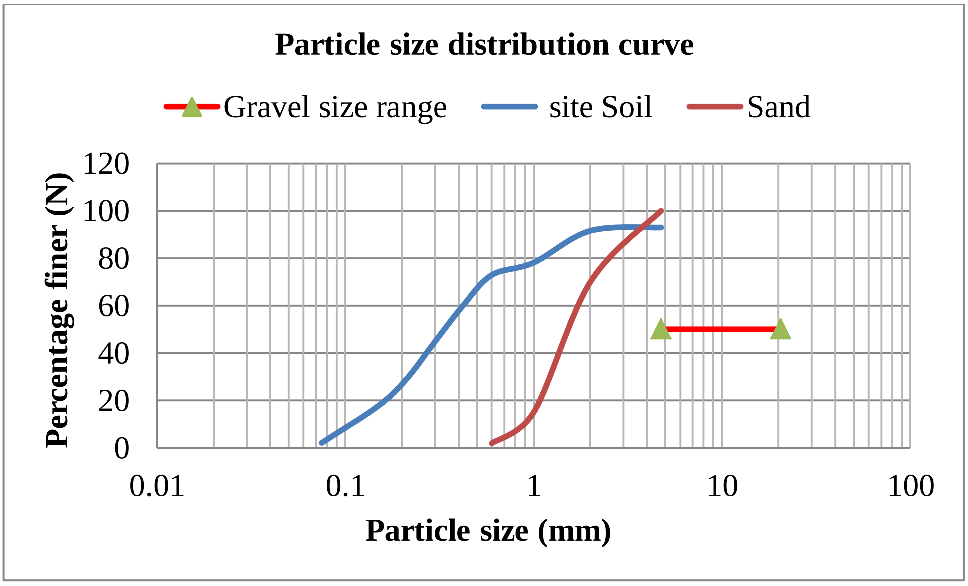

Figure 4.3 Particle size distribution curve

Gravel with size 10-20 mm is filled in the first chamber of the filter unit. And 40 mm gravel was selected to fill in the fourth chamber to allow the free flow of water towards the end of the filter set up.

4.8 STUDIES ON FILTER EFFICIENCIES

4.8.1 Hydraulic Efficiency

Constant inflow rate of 6.5 lps was given to the filter unit during the study and the outflow rate was calculated from the depth of flow over the V notch, and the hydraulic efficiency of each treatments was calculated by using the inflow and outflow rates. Mean values of outflow rate and the corresponding hydraulic efficiency values of each treatment are given in Table 4.4.

Table 4.4 Effect of filters on outflow rates and hydraulic efficiency

	T1F1	**T1F2**	**T1F3**	**T2F1**	**T2F2**	**T2F3**	**T3F1**	**T3F2**	**T3F3**
Outflow rate (lps)	2.41	1.51	3.98	5.26	4.07	5.27	5.02	3.92	5.93
Hydraulic efficiency (%)	37.91	23.28	61.63	80.47	62.94	82.56	77.38	60.65	90.2

The highest hydraulic efficiency (90.2%) was noted for the treatment T3F3 because of the high porosity and high surface area of charcoal over others and least value was noted as 23.28 per cent for treatment T1F2. Samuel *et al.* (2012) reported an average hydraulic efficiency for Gravel, Sand, and Coir fibre filter as 69.5 per cent. Statistical analysis was carried out for determining the effect of treatments on hydraulic efficiency and the results are given in the Table 4.5. Relationship between outflow rate and hydraulic efficiency of treatments were shown in Figure 4.4.

Table 4.5 ANOVA table of Hydraulic efficiency

Source	**Degrees of freedom**	**Mean square**	**P value**	**Calculated F Value**	
Factor T	2	2673.43	0.0000	365.2	**
Factor F	2	3354.94	0.0000	65.32	**
Factor T×F	4	516.331	0.0000	135.3	**

** Highly significant

The statistical analysis indicates that treatments were highly significant (P < 0.01) with 1 per cent level of significance.

4.8.2 Inflow Water Quality

Physical and chemical analysis of inflow water samples towards the filter and outflow from the filter were done in the laboratory of Nodal Water Technology Centre, KAU and Kerala Water Authority, Thrissur. Detailed data of the results are given in the Tables 4.6 and 4.7.

Table 4.6 Mean physical quality parameters of inflow

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
pH	8.53	7.62	6.73	6.94	7.76	6.85	8.19	8.51	6.90
EC (dS/m)	0.53	0. 52	0.57	0.60	2.90	0.34	2.43	0.44	0.65
TDS (ppm)	278	274.3	276	213.6	1533	184	262.3	1230	348.3
Salinity (ppt)	0.19	0.18	0.18	0.15	1.17	0.15	0.88	0.16	0.25
TSS (mg/l)	380	283.3	450	183.3	336	470	466.6	256.6	483
Turbidity (NTU)	115	82.97	143	48.63	93.3	135	67	59.47	145.7

If the inflow water turbidity is between 20 to 30 NTU, then vertical slow sand filters are suitable for treating the influent (Wegelin, 1996) (Galvis *et al*., 2006). Huisman *et al*. (1994) found that the better purification of vertical filters occurs when the turbidity is below 10 NTU. In other words, vertical slow sand filters need reasonably good inflow water and cannot be used for treating highly turbid water with turbidity greater than 50 NTU.

From Table 4.6, it was evident that the runoff collected from the site exhibited higher turbidity values which cannot be treated by vertical filters. In 1995, Tanveer Ahsan repoted that horizontal roughing filters will perform effectively to treat high turbid water (50 to 250 NTU) with better removal efficiencies. So the horizontal roughing filter designed for treating the runoff was found suitable for the area.

Table 4.7 Mean chemical quality parameters of the inflow

	T1F1	**T1F2**	**T1F3**	**T2F1**	**T2F2**	**T2F3**	**T3F1**	**T3F2**	**T3F3**
Acidity (mg/l)	12.0	16.3	14.7	9.3	14.7	12.3	25.3	28.3	24.0
Alkalinity (mg/l)	75.3	76.0	75.7	77.3	87.3	66.7	59.0	48.0	76.3
Total hardness (mg/l)	127.7	99.7	100.3	94.7	81.3	98.7	128.0	75.7	98.7
Calcium (mg/l)	37.2	44.4	33.4	35.3	36.5	33.3	40.3	27.2	27.4
Magnesium (mg/l)	3.9	3.5	4.3	3.8	4.4	3.8	7.3	7.7	6.9
Chloride (mg/l)	25.7	31.0	48.7	26.3	30.3	25.3	45.0	48.7	93.7
Fluoride (mg/l)	0.4	0.3	0.5	0.5	0.4	0.4	0.4	0.5	0.4

Iron (mg/l)	4.8	4.5	5.3	4.5	5.2	5.6	4.8	5.8	5.9
Nitrate (mg/l)	15.9	18.7	25.3	22.1	35.4	35.6	32.6	24.5	34.8
Sulphate (mg/l)	137.2	128.5	72.8	39.0	36.4	36.6	21.4	86.0	97.1

4.8.3 pH Normalising and EC Removal Efficiencies

From the chemical analysis of outflow water samples coming out of the filter unit removal efficiencies of pollutants was calculated as per the procedure described in chapter III. Calculated values of pH normalizing efficiency and EC removal efficiency for every treatment are shown in Table 4.8

Table 4.8 Effect of filters on pH normalising and EC removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
pH outflow	6.95	6.84	7.32	7.26	6.79	7.45	7.24	7.17	6.38
pH normalizing efficiency (%)	99.3	97.9	95.2	96.1	97.4	93.4	96.6	97.92	91.1
EC (dS/m) outflow	0.12	0.18	0.16	0.19	0.36	0.21	0.89	0.16	0.14
EC removal efficiency (%)	71.3	65.6	71.2	67.5	87.5	37.1	65.7	62.34	77.2

Higher pH normalisation efficiency value (99.38%) was noted for T1F1 treatment and the highest value of EC removal efficiency (87.57%) was noted for treatment T2F2. Charts related to the values are shown in Figure 4.5. Samuel *et al.* (2015) reported that a multi-layered vertical filter showed maximum of 78.66 per cent EC removal efficiency and maximum pH normalisation efficiency as 98.82 per cent.

Table 4.9 ANOVA table of pH normalising and EC removal efficiencies

ANOVA table of pH normalising efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	13.295	0.000	89.85	**
Factor F	2	56.99	0.000	385.25	**
Factor T×F	4	4.27	0.000	28.90	**
ANOVA table of EC removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	65.043	0.000	119.19	**
Factor F	2	355.72	0.000	651.90	**
Factor T×F	4	941.511	0.000	1725.42	**

** Highly significant

Statistical analysis showed that every treatment was highly significant on pH normalising efficiency and EC removal efficiency ($P < 0.01$) at 1 per cent level of significance.

4.8.4 TDS and Salinity Removal Efficiencies

TDS and salinity values of outflow water samples are found out and their removal efficiencies were calculated. It is shown in Table 4.10 and Figure 4.6.

Table 4.10 Effect of filters on TDS and salinity removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
TDS (ppm)	103	93	88.7	113	217	124.6	88.3	542.6	94
TDS removal efficiency (%)	62.2	66.1	67.8	47.1	85.8	32.5	66.2	55.8	73
Salinity (ppt)	0.06	0.07	0.06	0.08	0.18	0.09	0.43	0.09	0.06
Salinity removal efficiency (%)	66.1	59.1	67.3	43	84.4	42.2	51.6	46.8	75.6

Higher values of TDS removal efficiency (85.82%) and salinity removal efficiency (84.42%) were noted for T2F2 treatment.

Table 4.11 ANOVA table of TDS and salinity removal efficiencies

ANOVA table of TDS removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	305.61	0.0000	95.72	**
Factor F	2	1144.79	0.0000	358.57	**
Factor T×F	4	691.38	0.0000	216.55	**
ANOVA table of Salinity removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	146.42	0.0000	9.37	**
Factor F	2	249.13	0.0000	15.95	**
Factor T×F	4	1137.73	0.0000	72.85	**

** Highly significant

Statistical analysis showed that every treatment was highly significant ($P < 0.01$) on salinity removal efficiency at 1 per cent level of significance.

4.8.5 TSS and Turbidity Removal Efficiencies

Mean values of TSS and turbidity removal efficiencies of treatments are shown in Table 4.12.

Table 4.12 Effect of filters on TSS and Turbidity removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
TSS (mg/l) outflow	96.6	50	120	50	50	50	26.6	13.3	23.3
TSS removal efficiency (%)	74.5	82.3	73.3	72.7	85.1	90.4	94.6	94.2	95.1
Turbidity (NTU) Outflow	27.8	15.4	34.5	13.6	14.7	14	3.5	3.1	3.1
Turbidity removal efficiency (%)	75.8	81.6	75.8	71.8	84.9	89.5	94.7	94.6	97.9

Higher TSS removal efficiency (95.18%) and Turbidity removal efficiency (97.95%) was found for T3F3 combination. Patil *et al.* (2012) reported that a horizontal filter showed 90 per cent TSS removal efficiency and Losleben (2004) stated that a horizontal filter unit in which only gravel medium was used as filter material showed 50 per cent of turbidity removal efficiency. Similar results were obtained for the TSS removal efficiency value and the Turbidity removal was progressively improved with charcoal treatment. Mean values were shown in Figure 4.7.

Table 4.13 ANOVA table of TSS and Turbidity removal efficiencies

ANOVA table of TSS removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	640.23	0.000	467.29	**
Factor F	2	38.97	0.000	28.44	**
Factor T×F	4	96.89	0.000	70.72	**
ANOVA table of Turbidity removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	1074.66	0.0000	271.13	**
Factor F	2	711.70	0.0000	179.56	**
Factor T×F	4	720.83	0.0000	181.86	**

** Highly significant

Statistical analysis showed that each treatment was highly significant ($P < 0.01$) at 1 per cent level of significance.

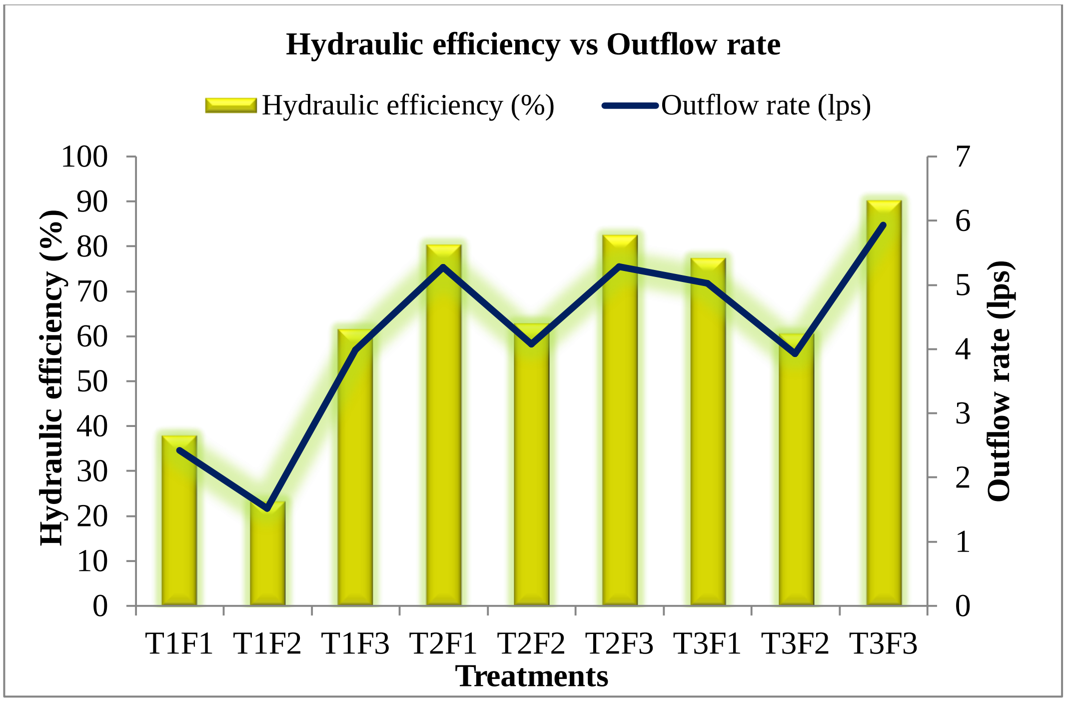

Figure 4.4 Hydraulic efficiency and Outflow rate

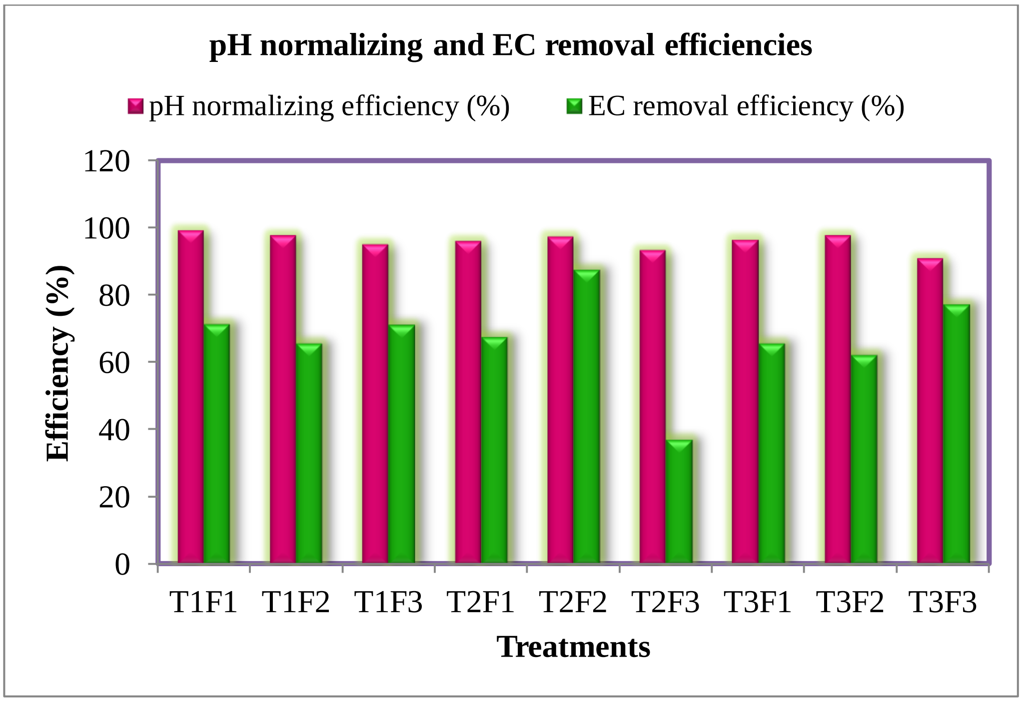

Figure 4.5 pH normalising and EC removal efficiencies

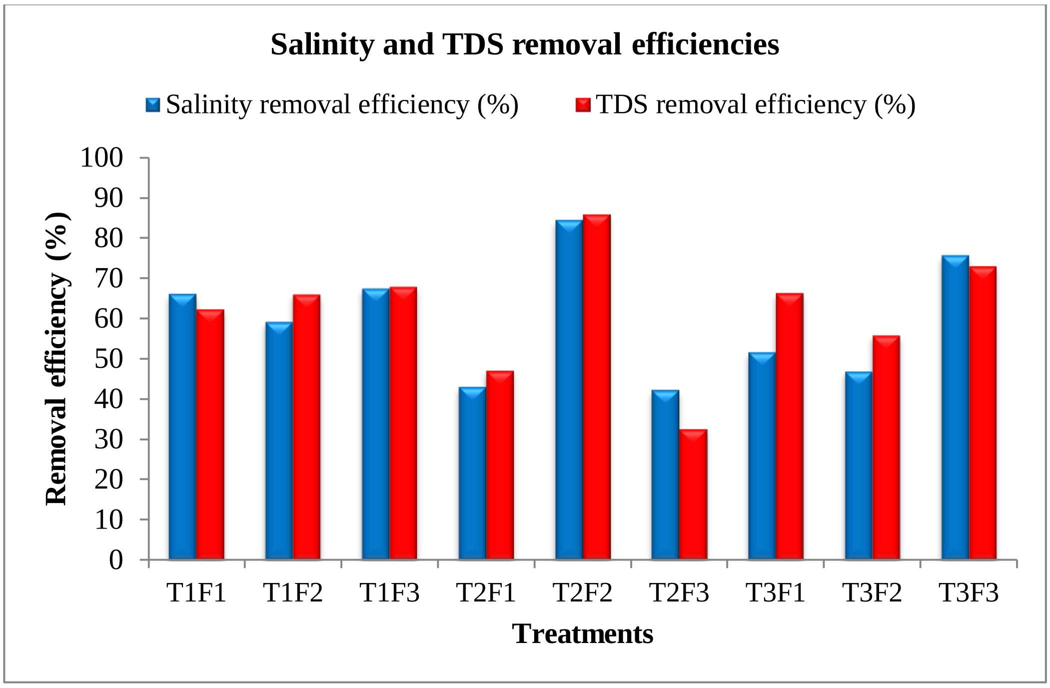

Figure 4.6 Salinity and TDS removal efficiencies

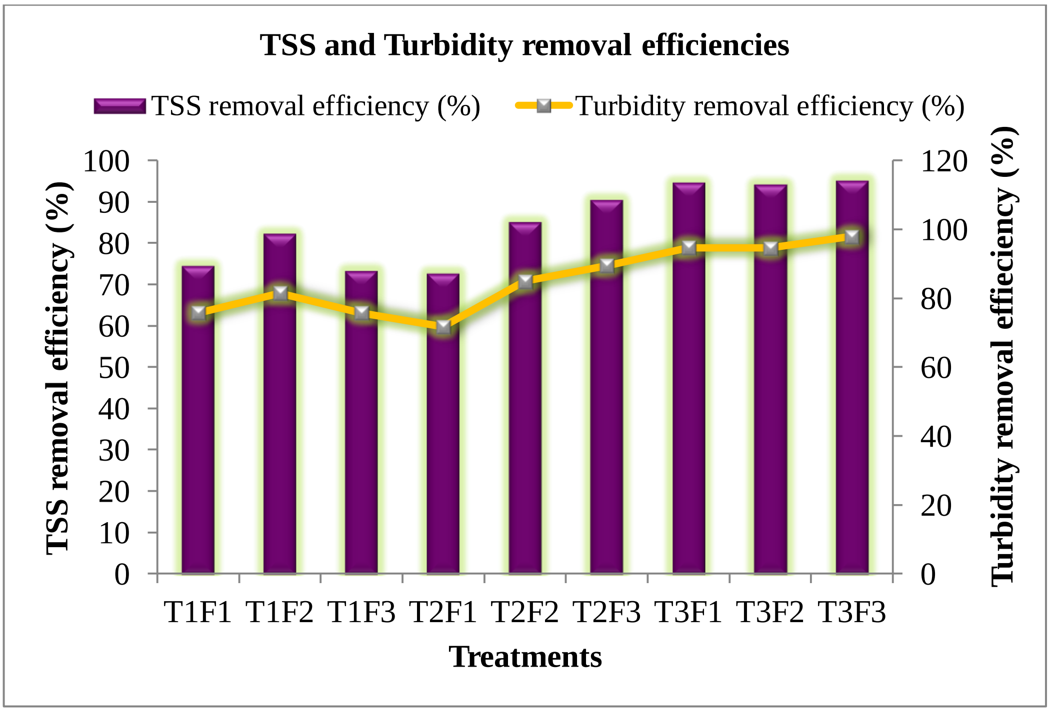

Figure 4.7 TSS and Turbidity removal efficiencies

4.8.6 Acidity and Alkalinity Removal Efficiencies

Table 4.14 Effect of filters on acidity and alkalinity removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
Acidity (mg/l)	7	8.67	11	6.33	7.33	9.3	14	18.33	11.67
Acidity removal efficiency (%)	41.5	47.1	25	31.5	50.6	23.8	44.8	35.76	51.51
Alkalinity (mg/l)	43.3	44.3	37	53	60.6	34.6	14.3	21.33	16.00
Alkalinity removal efficiency (%)	42.5	41.6	50.7	31.4	30.3	48.0	75.9	55.69	79.24

Highest value of acidity removal efficiency (51.51%) was found for treatment T3F3 and the lowest value (14.76%) for treatment T2F3. But the highest value of alkalinity removal efficiency (79.24%) was found for treatment T3F3 and least (30.3%) for treatment T2F2. Mean values of the efficiencies are shown in Figure 4.8.

Table 4.15 ANOVA table of Acidity and Alkalinity removal efficiencies

ANOVA table of Acidity removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	390.78	0.0000	25.68	**
Factor F	2	880.14	0.0000	57.84	**
Factor T×F	4	2364.76	0.0000	155.41	**

ANOVA table of Alkalinity removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	4111.28	0.0000	620.09	**
Factor F	2	2641.39	0.0000	398.39	**
Factor T×F	4	391.57	0.0000	59.06	**

**.Highly significant

Statistical analysis showed that each treatment was highly significant ($P < 0.01$) at 1 per cent level of significance.

4.8.7 Total Hardness and Calcium Removal Efficiencies

Total hardness removal efficiency in terms of $CaCO_3$ and Calcium removal efficiency was found out by analyzing the inflow and outflow water quality parameters (Table 4.16 and Figure 4.9).

Table 4.16 Effect of filter on total hardness and calcium removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
Total hardness (mg/l)	39.3	33	6.7	15.4	16	12.7	18.2	20.74	8.79
Total hardness removal efficiency (%)	69.2	66.7	93.3	83.9	80.8	87	85.7	73.40	91.03
Calcium (mg/l)	6	8.9	5.3	11.2	8.8	13.5	12.7	11.07	4.90
Calcium removal efficiency (%)	83.6	79.9	83.9	68	75.7	59.5	68.3	59.20	82.15

Highest value of calcium removal efficiency (83.9%) and the highest hardness removal efficiency (93.3%) was exhibited by T1F3 treatment.

Table 4.17 ANOVA table of Total Hardness and Calcium removal efficiencies

ANOVA table of Total Hardness removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	157.67	0.862	0.26	NS
Factor F	2	605.78	0.38	1.01	*
Factor T×F	4	156.31	0.864	0.26	NS
ANOVA table of Calcium removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	916.84	0.0000	75.91	**
Factor F	2	670.606	0.0000	55.52	**
Factor T×F	4	491.86	0.0000	40.72	**

NS: Not significant

* Significant

** Highly significant

Statistical analysis showed that the treatments have no significant difference over total hardness removal efficiency because $P > 0.05$, but treatments is highly significant in terms of Calcium removal efficiency ($P < 0.01$) at 1 per cent level of significance.

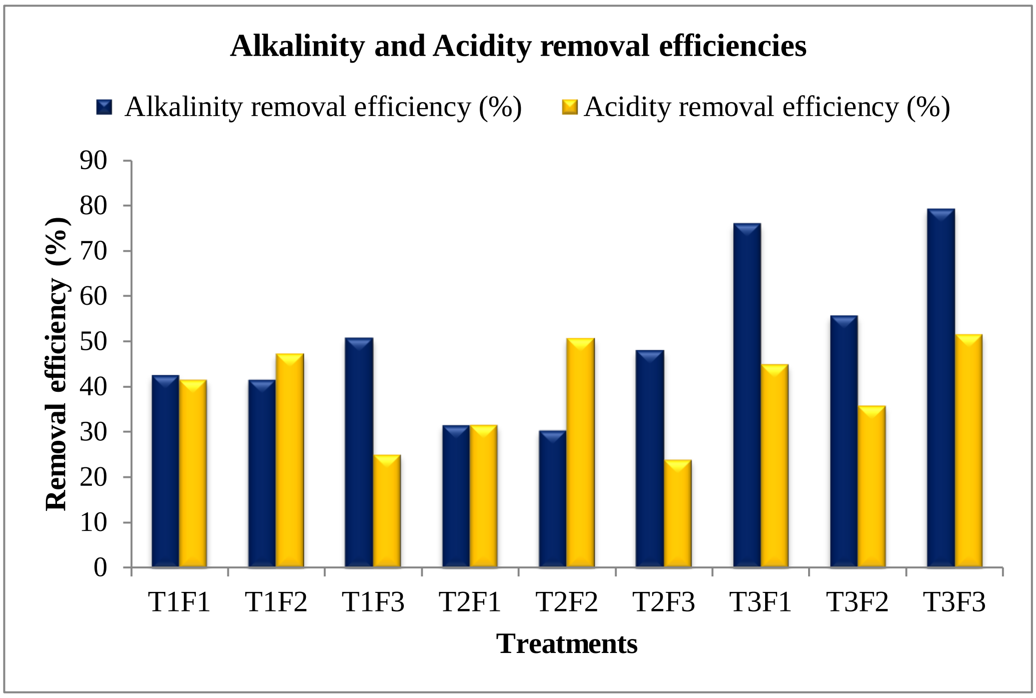

Figure 4.8 Alkalinity and Acidity removal efficiencies

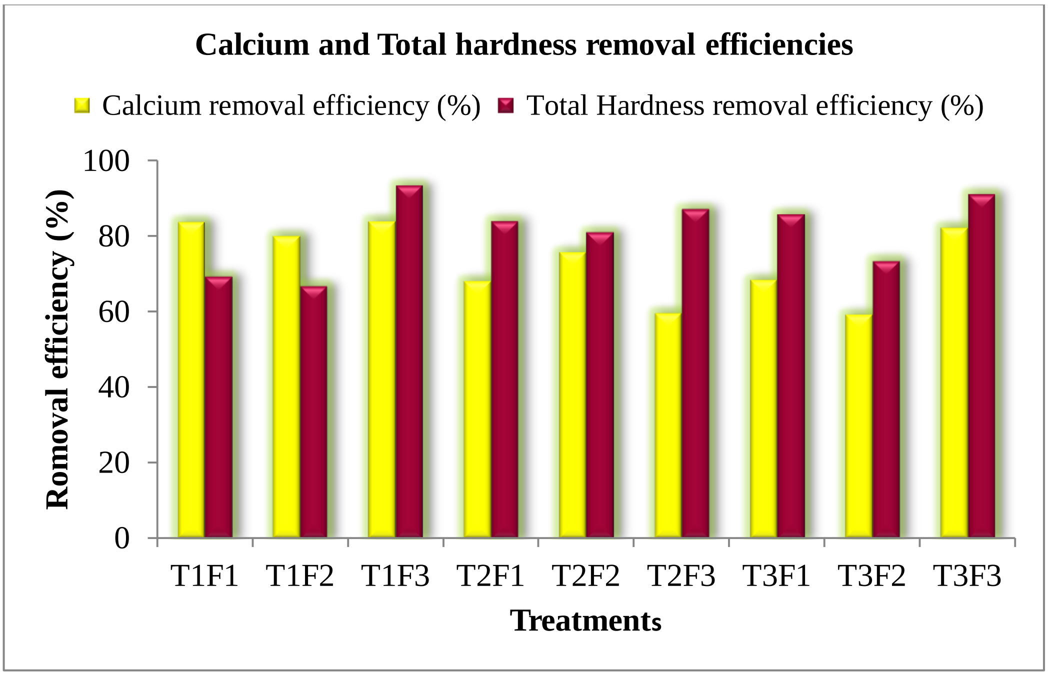

Figure 4.9 Calcium and hardness removal efficiencies

4.8.8 Magnesium and Chloride Removal Efficiencies

Based on the concentration of magnesium and chloride in the inflow and outflow water samples collected, removal efficiencies of these parameters were found out and are given in Table 4.18 and Figure 4.10.

Table 4.18 Effect of filters on Magnesium and Chloride removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
Magnesium (mg/l)	2.27	2.6	2.37	1.47	2.47	1.70	5.40	6.13	4.13
Magnesium removal efficiency	41.9	25.2	45.2	61.3	44.3	55.6	25.6	20	39.1
Chloride (mg/l)	13.6	16.6	22.6	20	20.3	21	23.6	28.3	57.6
Chloride removal efficiency (%)	46.4	46	53.4	23.1	32.3	17.0	47.6	41.5	38.9

Highest value of magnesium removal efficiency (61.32%) was found out for T2F1 treatment and the highest value of chloride removal efficiency (53.4%) was found out for T1F3 treatment.

Table 4.19 ANOVA table of Magnesium and Chloride removal efficiencies

ANOVA table of Magnesium removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	1524.84	0.0000	134.07	**
Factor F	2	1912.96	0.0000	168.19	**
Factor T×F	4	1236.83	0.0000	108.74	**

ANOVA table of Chloride removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	359.32	0.0000	21.18	**
Factor F	2	1902.077	0.0000	112.11	**
Factor T×F	4	1874.78	0.0000	110.50	**

** Highly significant

Statistical analysis showed that each treatment was highly significant ($P < 0.01$) at 1 per cent level of significance.

4.8.9 Fluoride and Iron Removal Efficiencies

Table 4.20 Effect of filters on Fluoride and Iron removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
Fluoride (mg/l)	0.30	0.22	0.37	0.39	0.31	0.27	0.24	0.32	0.22
Fluoride removal efficiency (%)	18.0	22.2	17.6	20.9	13	25.5	35.43	29.55	40.16
Iron (mg/l)	2.50	2.10	2.93	2.13	2.57	2.17	1.23	1.20	1.17
Iron removal efficiency (%)	47.8	53.0	44.6	52.2	50.9	61.6	74.84	79.77	80.55

Highest value of fluoride removal efficiency (40.16%) and iron removal efficiency (80.55%) was found out for T3F3 treatment. Mean value charts are represented graphically in Figure 4.11.

Table 4.21 ANOVA table of Fluoride and Iron removal efficiency

ANOVA table of Fluoride removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	2006.77	0.0000	62.83	**
Factor F	2	2274.13	0.0000	71.20	**
Factor T×F	4	752.28	0.0000	23.55	**
ANOVA table of Iron removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	3116.87	0.0000	881.62	**
Factor F	2	93.77	0.0000	26.52	**
Factor T×F	4	1210.93	0.0000	342.52	**

** Highly significant

Statistical analysis showed that each treatment was highly significant ($P < 0.01$) at 1 per cent level of significance.

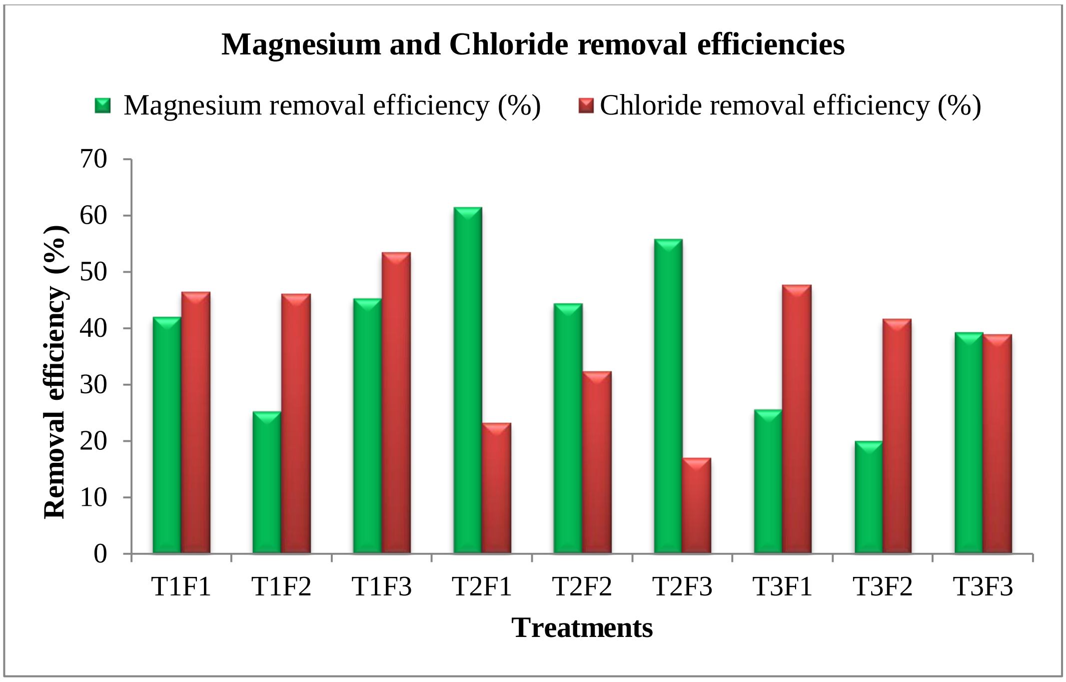

Figure 4.10 Magnesium and Chloride removal efficiencies

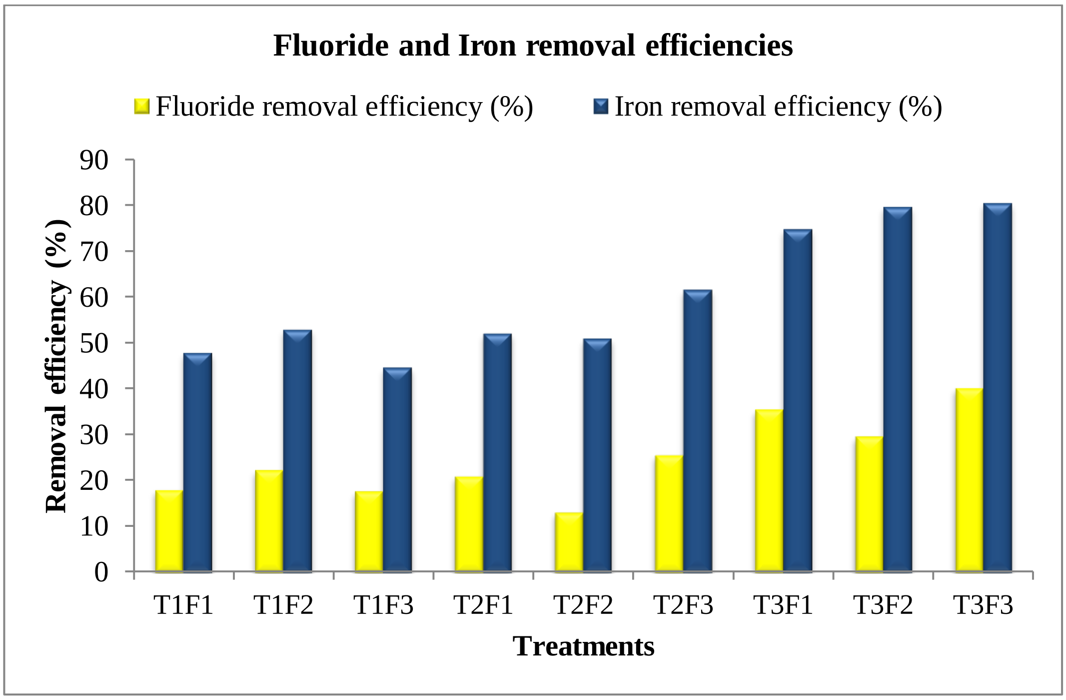

Figure 4.11 Fluoride and Iron removal efficiencies

4.8.10 Nitrate and Sulphate Removal Efficiencies

Table 4.22 Effect of filters on Nitrate and sulphate removal efficiencies

	T1F1	T1F2	T1F3	T2F1	T2F2	T2F3	T3F1	T3F2	T3F3
Nitrate (mg/l)	6.53	6.77	14.5	11.4	15.4	20.9	20.8	13.3	16.40
Nitrate removal efficiency (%)	58.8	63.8	42.5	48.3	53.4	41.0	45.5	36	52.76
Sulphate (mg/l)	12.8	10.9	10.1	12.7	6.97	15.9	10.3	38.8	56.67
Sulphate removal efficiency (%)	90.6	91.4	86.5	67.4	80.1	56.4	51.7	54.7	41.48

Highest value of nitrate removal efficiency (63.79%) was found for T1F2 treatment and highest sulphate removal efficiency (91.46%) was found for T1F2 treatment. Data pertaining to these efficiencies are shown in Figure 4.12. Samuel *et al.* (2012) reported average nitrate removal efficiency for Gravel, Sand, Coir fibre filter was 66.36 per cent and average sulphate removal efficiency for Gravel, Sand, and Coir fibre filter as 77.98 per cent.

Table 4.23 ANOVA table of Nitrate and Sulphate removal efficiencies

ANOVA table of Nitrate removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	515.66	0.0000	146.02	**
Factor F	2	747.65	0.0000	211.71	**
Factor T×F	4	602.07	0.0000	170.49	**

ANOVA table of Sulphate removal efficiency					
Source	**Degrees of freedom**	**Mean square**	**P value**	**F Value**	
Factor T	2	4776.96	0.0000	5899.07	**
Factor F	2	1438.112	0.0000	1775.92	**
Factor T × F	4	508.98	0.0000	628.54	**

** Highly significant

4.9 FILTRATION VELOCITY

From the Figure 4.13, it is noted that T3F3 treatment showed highest filtration velocity value with highest hydraulic efficiency. It may due to the high porosity of the charcoal medium over others.

The analysis of the outflow samples from all treatments showed that the concentration of all chemical parameters were found in safe concentration level as indicated by IS: 10500–2012.

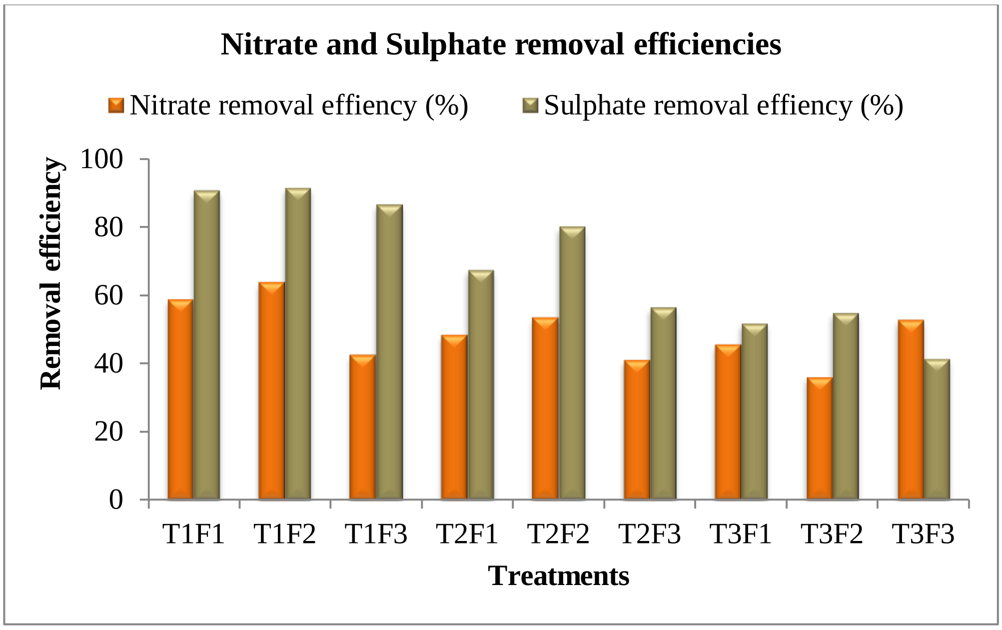

Figure 4.12 Nitrate and Sulphate removal efficiencies

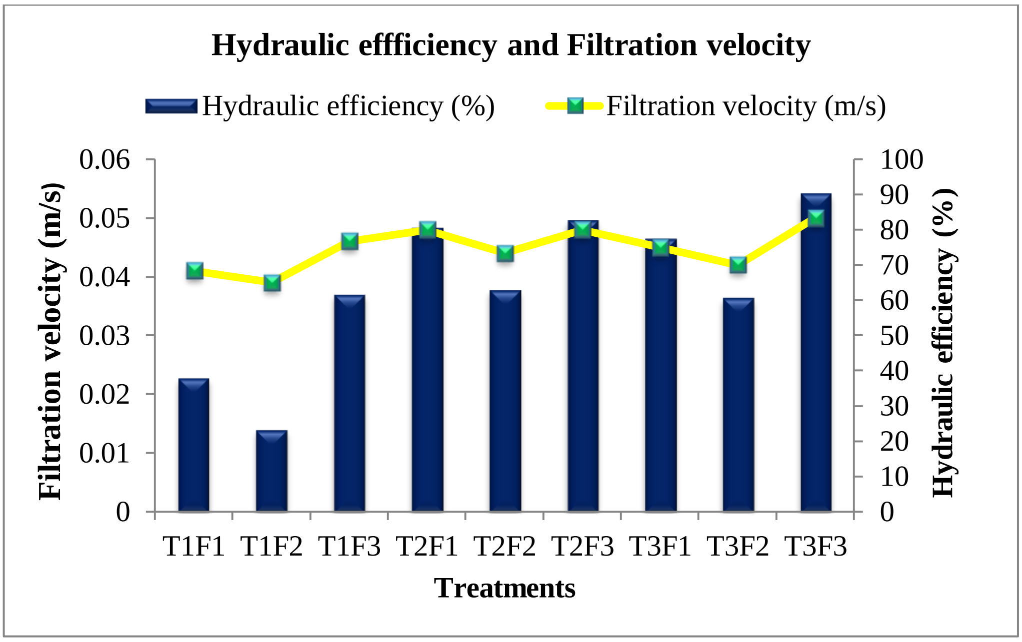

Figure 4.13 Filtration velocity of treatments

4.10 SELECTION OF BEST FILTER MEDIA COMBINATION

It was unable to select one particular treatment combination based on the results because different treatment combinations performed differently over various filter efficiencies. In this condition Duncan's Multiple Range Test (DMRT) was performed for selecting the better treatment based on those efficiencies which have significant effect on filter performance. Ranking was done for each efficiency mean values and the highest value got 'a' rank and the ranking value '1'. Following were marked with rank 'b', 'c', 'd etc. and rank values '2', '3', '4' respectively. Rank values of each treatment were added together and the treatment that obtained the lowest overall rank value was selected as best treatment combination. It is shown in the Table 4.24.

Table 4.24 DMRT result of mean filter performance

Treatment	**pH normalizing efficiency (%)**	**EC removal efficiency (%)**	**TDS removal efficiency (%)**	**Salinity removal efficiency (%)**	**TSS removal efficiency (%)**	**Turbidity removal efficiency (%)**	**Acidity removal efficiency (%)**	**Alkalinity removal efficiency (%)**
T1F1	99.38^{a}_{1}	71.36^{c}_{3}	62.24^{d}_{4}	66.07^{c}_{3}	74.54^{g}_{7}	75.8^{c}_{3}	41.50^{c}_{3}	42.52^{e}_{5}
T1F2	97.94^{b}_{2}	65.67^{e}_{5}	66.04^{c}_{3}	59.07^{d}_{4}	82.34^{e}_{5}	81.57^{b}_{2}	$47.17^{bc}_{2.5}$	41.62^{e}_{5}
T1F3	95.2^{d}_{4}	71.28^{c}_{3}	67.86^{c}_{3}	67.34^{c}_{3}	73.32^{g}_{7}	75.83^{c}_{3}	$25^{de}_{4.5}$	50.75^{c}_{3}
T2F1	96.15^{c}_{3}	67.54^{d}_{4}	47.04^{f}_{6}	43.01^{f}_{6}	72.70^{g}_{7}	71.8^{c}_{3}	31.56^{d}_{4}	31.48^{f}_{6}
T2F2	97.42^{b}_{2}	87.57^{a}_{1}	85.82^{a}_{1}	84.42^{a}_{1}	85.14^{d}_{4}	84.98^{b}_{2}	50.62^{a}_{1}	29.34^{g}_{7}
T2F3	93.41^{e}_{5}	37.13^{h}_{8}	32.50^{g}_{7}	42.20^{f}_{6}	90.48^{c}_{3}	89.57^{b}_{2}	23.88^{e}_{5}	48.07^{d}_{4}
T3F1	96.63^{c}_{3}	65.75^{d}_{4}	66.27^{c}_{3}	51.69^{e}_{5}	94.67^{b}_{2}	94.78^{a}_{1}	$44.84^{bc}_{2.5}$	75.93^{a}_{1}
T3F2	97.92^{b}_{2}	62.34^{f}_{6}	55.85^{e}_{5}	$46.81^{ef}_{5.5}$	94.24^{b}_{2}	94.67^{a}_{1}	35.76^{f}_{6}	55.69^{c}_{3}
T3F3	91.10^{f}_{6}	77.23^{b}_{2}	73.01^{b}_{2}	75.66^{b}_{2}	95.18^{a}_{1}	97.95^{a}_{1}	51.5^{a}_{1}	79.24^{a}_{1}

Treatment	Calcium removal efficiency (%)	Magnesium removal efficiency (%)	Chloride removal efficiency (%)	Fluoride removal efficiency (%)	Iron removal efficiency (%)	Nitrate removal efficiency (%)	Sulphate removal efficiency (%)	Hydraulic Efficiency (%)
T1F1	83.68^{a} 1	41.91^{c} 3	46.40^{b} 2	18.01^{d} 4	47.88^{de} 4.5	58.82^{b} 2	90.64^{a} 1	37.91^{e} 5
T1F2	79.97^{ab} 1.5	25.24^{e} 5	46.06^{b} 2	22.26^{cd} 3.5	52.99^{d} 4	63.79^{a} 1	91.46^{a} 1	23.28^{f} 6
T1F3	83.92^{a} 1	45.22^{c} 3	53.43^{a} 1	17.67^{d} 4	44.65^{e} 5	42.54^{e} 5	86.57^{b} 2	61.63^{d} 4
T2F1	68.08^{c} 3	61.32^{a} 1	23.17^{e} 5	20.98^{cd} 3.5	52.20^{d} 4	48.33^{d} 4	67.44^{c} 3	80.47^{b} 2
T2F2	75.73^{b} 2	44.39^{c} 3	32.35^{d} 4	13.08^{d} 4	50.95^{d} 4	53.47^{c} 3	80.10^{b} 2	62.94^{d} 4
T2F3	59.51^{d} 4	55.67^{b} 2	17.01^{f} 6	25.58^{c} 3	61.66^{c} 3	41.06^{e} 5	56.41^{d} 4	82.56^{b} 2
T3F1	68.32^{c} 3	25.63^{e} 5	47.64^{b} 2	35.55^{b} 2	74.83^{a} 1	45.51^{de} 4.5	51.79^{d} 4	77.38^{bc} 2.5
T3F2	59.19^{d} 4	20.06^{f} 6	41.59^{c} 3	29.42^{c} 3	79.76^{a} 1	36.04^{f} 6	54.77^{d} 4	60.65^{d} 4
T3F3	82.14^{a} 1	39.17^{c} 3	38.92^{d} 4	40.15^{a} 1	80.55^{a} 1	52.75^{c} 3	41.48^{e} 5	90.2^{a} 1

Criteria for ranking: a = 1, b = 2, c = 3, d = 4, e = 5, f = 6, g =7, h = 8, ab = 1.5, bc = 2.5, cd = 3.5, de = 4.5, ef = 5.5, fg = 6.5

Rank values of efficiencies corresponding to the specific treatments were added together and the overall rank value of treatments were found out. Data is given in Table 4.25.

Table 4.25 Overall rank values of treatments

Treatment	**Total Rank Value**
T1F1	51.5
T1F2	52.5
T1F3	56.5
T2F1	51.5
T2F2	45
T2F3	72
T3F1	48.5
T3F2	61.5
T3F3	35

4.11 TESTING IN THE ACTUAL RAINY CONDITION

Results obtained from the DMRT test showed that the T3F3 treatment got lowest overall rank value 35 and this filter performed well during the experiment and T2F2 treatment was ranked second. Those two treatments were again tested in the actual rainy conditions for selecting the best one for treating the storm water runoff. The water samples were analysed for both physical and chemical pollutant removal efficiencies. The results obtained are depicted in Tables 4.26, 4.27 and Figure 4.14.

Table 4.26 Physical parameters and their removal efficiencies

Parameter	T3F3 Gravel (80 cm),Charcoal (100 cm), Sand (60 cm) and Gravel (80 cm)	T2F2 Gravel (80 cm), Sand (100 cm), Synthetic fibre (60 cm) and Gravel (80 cm)
pH (inflow)	7.7	8.0
pH (outflow)	7.0	7.2
pH normalisation efficiency (%)	99.6	97.3
EC (dS/m) (inflow)	0.07	0.015
EC (dS/m) (outflow)	0.04	0.014
EC removal efficiency (%)	32.1	8.4
Salinity (ppt) (inflow)	0.0	0.0
Salinity (ppt) (outflow)	0.0	0.0
Salinity removal efficiency (%)	38.9	0.0
TDS (ppm) (inflow)	37.3	8.2
TDS (ppm) (outflow)	25.0	7.1
TDS removal efficiency (%)	32.9	13.6
TSS (mg/l) (inflow)	530.0	493.3
TSS (mg/l) (outflow)	50.0	176.7
TSS removal efficiency (%)	90.6	64.1
Turbidity (NTU) (inflow)	180.3	150.0
Turbidity (outflow)	11.9	55.0
Turbidity removal efficiency (%)	93.4	63.3

Table 4.27 Chemical parameters and their removal efficiencies

Parameter	T3F3 Gravel (80cm), Charcoal (100 cm), Sand (60 cm) and Gravel (80 cm)	T2F2 Gravel (80 cm), Sand (100 cm), Synthetic fibre (60 cm) and Gravel (80 cm)
Acidity (mg/l) inflow	8	34.3
Acidity (mg/l) outflow	6	5.7
Acidity removal efficiency (%)	25	83.5
Alkalinity (mg/l) inflow	15.7	14.7
Alkalinity (mg/l) outflow	5.0	8.0
Alkalinity removal efficiency (%)	68.3	43.9
Calcium (mg/l) inflow	4.3	4.0
Calcium (mg/l) outflow	1.6	4.0
Calcium removal efficiency (%)	62.7	0.0
Magnesium (mg/l) inflow	1.7	0.4
Magnesium (mg/l) outflow	0.9	0.4
Magnesium removal efficiency (%)	43.8	0.0
Chloride (mg/l) inflow	12.0	11.7
Chloride (mg/l) outflow	9.3	9.7
Chloride removal efficiency (%)	22.1	17.4
Fluoride (mg/l) inflow	0.4	0.3
Fluoride (mg/l) outflow	0.1	0.0
Fluoride removal efficiency (%)	72.2	89.9
Iron (mg/l) inflow	9.3	10.3
Iron (mg/l) outflow	1.3	5.3
Iron removal efficiency (%)	85.8	48.1

Nitrate (mg/l) inflow	7.7	4.7
Nitrate (mg/l) outflow	1.3	1.0
Nitrate removal efficiency (%)	83.6	78.2
Sulphate (mg/l) inflow	1.8	2.3
Sulphate (mg/l) outflow	1.3	2.0
Sulphate removal efficiency (%)	27.4	12.6

Except the acidity and fluoride removal efficiencies, regarding all other parameters, charcoal performed well. So the treatment T3F3 was selected for installing in the filter bed.

4.12 INSTALLATION OF THE SELECTED MEDIA

The selected best filter media combination for treating the storm water runoff, Gravel (80 cm), Charcoal (100 cm), Sand (60 cm) and Gravel (80 cm) (treatment T3F3) was installed in field experimental setup for recharging the groundwater and it is shown in Plate 4.2.

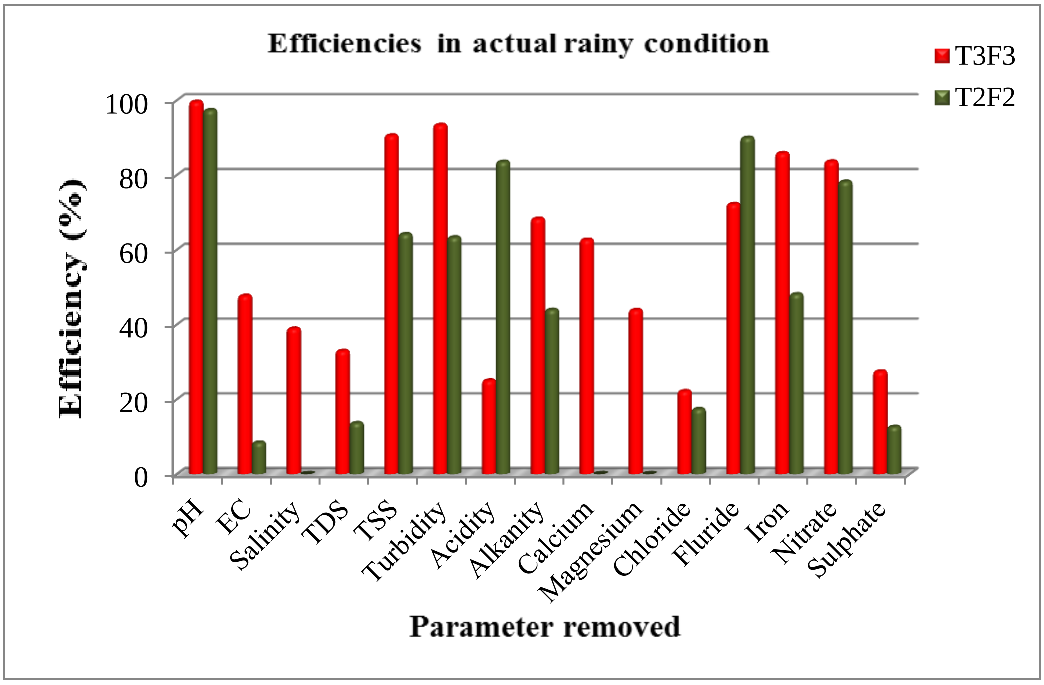

Figure 4.14 Pollutant removal efficiencies of filter tested in rainy condition

Plate 4.2 View of installed medium combination in the filter unit

4.13 RECHARGE THROUGH ABANDONED TUBE WELL

After installing the selected media combinations in the filter bed, perforations were made on the exposed portion of the tube well casing pipe by using drill bit. 54 perforations were made in 12 mm size up to 50 cm height of the pipe from the bottom of the collecting chamber. Again it was wrapped with nylon net to prevent the entry of fine particles into the well.

For measuring the water entering rate to the tube well, the perforations were closed by plastic sheet. After collecting 35 cm of depth of filtered water in the collecting tank, sheet was removed and the time taken for recharge was noted down by using a stop watch.

Measured water entering rate

$= (1.95 \times 1.95 \times 0.35)\ m^3/130\ sec$

$= 10.22$ lps

The measured water entering rate was found as 10.22 lps which was a reasonably good value. Kaledhonkar *et al.* (2002) conducted a study on artificial recharge through tube wells and he observed an average recharge rate of 10.5 lps through individual tube wells.

4.14 COST OF INSTALLATION OF THE FILTER UNIT

Cost incurred for the construction of the filter unit and installation of the best medium combination was calculated and the value calculated was Rs.51000 (Table 4.28).

Table 4.28 Cost of installation of the filter unit

Cost of construction of the filter unit with settling tank	Rs. 35000
Cost of construction of separation frames, roofing, channel lining, notches	Rs. 5000
Cost of gravel filter medium	Rs. 3000
cost of sand filter medium	Rs. 2000
Cost of charcoal filter medium	Rs. 2000
Washing and Filling charges	Rs. 1000
Total cost	**Rs. 51000**

Frequent backwashing and cleaning can be done and the charcoal can be activated as activated charcoal. So no replacement cost of filter materials will be encountered for the remaining life years. With an average annual rainfall of 2795 mm in the study area, a runoff depth of 1118 mm can be expected (Runoff coefficient is taken as 0.3). Accordingly a runoff volume of 2.3 million litres of water can be diverted from the study area to the recharge well annually. Comparison of this enormous benefit from the artificial recharge structure with the cost incurred is indicating the promising future of the artificial recharge.

CHAPTER-5

Summary and Conclusions

CHAPTER V

SUMMARY AND CONCLUSION

Large scale draft from groundwater resources for fulfilling agricultural and industrial needs lead to the decline of groundwater levels in an alarming rate. So it is essential to replenish these dried out aquifers by adopting artificial recharge methods. Artificial recharge through tube wells with proper filtration mechanisms is a promising method because it will ensure the direct recharge of depleted aquifers without any significant losses.

Field experiment of the design and evaluation of the horizontal filter unit for groundwater recharge through abandoned tube well was conducted in the research field of Nodal Water Technology Centre, CoH Vellanikkara during 2015 December to 2016 June.

Suitability of the tube well for recharging the groundwater was done by the analysis of the result of electrical resistivity measurement done by the Department of Groundwater, Thrissur. The results showed that the subsurface layers are formed of good percentage of sand, gravel, clay etc. So the aquifer exhibits its better capability for recharge.

From the rainfall–recharge relationship calculated by using the empirical equations, it was observed that about 70 per cent of the total rainfall is lost as surface runoff from the study area. So it is better to manage this large amount of water lost and utilize it for recharging the groundwater through the abandoned tube well located in the site. Recharging can be done only after treating the runoff for removing the pollutants present in it to ensure the quality of the recharging water and to avoid the clogging while recharging.

By the comparison of the peak runoff expected from the area and the carrying capacity of the existing conveying channel, it was observed that the channel has sufficient capacity to handle the peak runoff expected from the area. Thus the existing channel was modified to construct a filter unit for treating runoff and a recharging section.

A masonry structure with 6.5 m length, 60 cm width and 50 cm depth below the ground surface was constructed in the existing conveying channel. It was then divided into components like a settling tank, filter unit with 5 compartments and a collecting tank. The upstream portion of the channel was kept for diverting the flow towards the filter bed and it was lined for preventing scouring.

Filter materials for filling in the four chambers were selected as Gravel, Sand, Charcoal/Synthetic fibre/Coir fibre. These different combinations were fixed as experimental treatments. Size selection of the gravel filter media and sand media were done on the basis of standard USBR criteria. Lengths of filling different media were changed while conducting the experiment by changing the position of the partition mesh frames in the slots made on the filter bed. Varied length of filling was fixed as factors. Three sets of length variation in three different media combinations were selected as experimental trials.

Effect of these treatments in the filter performance efficiencies were analysed by creating artificial runoff in the field itself. Water samples were collected and analysed for physical and chemical parameters. Hydraulic performance and pollutant removal efficiencies of the filter for each trial were calculated and they were analysed by using FCRD test with three replication values.

Treatment T1F1 was better in pH normalising efficiency, T1F2 removed Nitrate and Sulphates effectively, T1F3 was better in Total hardness and Calcium removal efficiency, T2F1 performed well for Magnesium and Chloride removal efficiencies. Treatments T2F2 and T3F3 was effective for EC, TDS, Salinity, TSS, Turbidity, Acidity, Fluoride, Alkalinity, Iron removal and Hydraulic efficiencies.

Except total hardness removal efficiency, all other pollutant removal efficiencies exhibited high significance between treatments with 1 per cent level of significance. Mean value charts were prepared for each performance efficiencies obtained from the ANOVA and it was observed that different treatments performed well over different efficiencies.

DMRT test was again performed over those efficiencies to select the best treatment. For this, ranking has been given to the efficiency values as highest value given rank ‘a’ with rank value 1. It has been followed by ranks ‘b’, ‘c’, ‘d’ etc. with values ‘2’, ‘3’, ‘4’ etc. Overall rank values for each treatments was calculated and it was found less (35) for the treatment T3F3 (gravel (80 cm), Charcoal (100 cm), Sand (60 cm) and Gravel (80 cm) and followed by T2F2 (gravel (80 cm), Sand (100 cm), Synthetic fibre (60 cm), Gravel (80 cm) with overall rank value 45.

These two treatment combinations were again field tested in the actual rainy condition. Charcoal combination performed well for turbidity removal efficiency, TSS removal efficiency, TDS removal efficiency, iron removal efficiency etc. But synthetic fibre combination showed better fluoride and acidity removal efficiency. Among them charcoal combination was selected for installing in the filter unit due to its better filter performance and availability at low cost.

Selected filter media combination in the selected length was installed in the filter unit. For recharging the treated water coming out of the filter unit, through the extended portion of the pipe, perforations with aperture 12 mm was drilled on the pipe up to 50 cm from the collecting tank bottom. Water recharge rate was monitored for three consecutive days and the rate observed was 10.22 lps. There was no lagging or ponding of water in the collecting tank.

The observed rate of entry of water to the tube well under experiment is a satisfactory value while considering the depleting aquifer status all over India. Not only for tube wells but also for abandoned open wells we can adopt the artificial recharge methods. If we are utilizing the unused 10.5 lakh open wells and tube wells in Kerala (Sreeraj, 2016) for artificial recharge, huge amount of water can be restored in the groundwater annually. It will improve the groundwater potential of the Kerala state for future benefits.

Suggestions for future work:

1. Study on the relationship between rainfall occurring in the area and the recharge rate through the tube well.
2. Study on the effect of artificial recharge through this abandoned tube well on the improvement of the water table of the area.
3. Modelling rainfall-runoff - recharge nexus and quality - quantity paradigm.

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Appendices

APPENDIX I

Determination of Infiltration rate

Elapsed time (min)	Interval (min)	Distance of water surface from reference point			Infiltration during period	
		Initial depth (cm)	Final depth (cm)	Decrease in water level (cm)	Average rate (cm / hr)	Accumulated infiltration (cm)
	-	15.0	-	-	-	-
5	5	15	4.5	10.5	126	10.5
10	5	15	4.4	10.6	127.2	21.1
15	5	15	4.4	10.6	127.2	31.7
25	10	15	4.7	10.3	61.8	42
45	20	15	4.5	10.5	31.5	52.5
60	15	15	4.2	10.8	43.2	63.3
75	15	15	4.1	10.9	43.6	84.7
90	15	15	3.9	11.1	44.4	85.3
110	20	15	3.9	11.1	33.3	96.4
130	20	15	3.7	11.3	33.9	107.7
160	30	15	3.7	11.3	22.6	119
190	30	15	3.9	11.1	22.2	130.1
240	50	15	3.9	11.1	13.32	141.2

APPENDIX II

Determination of soil texture

Sl. No	Sieve	Particle Size D(mm)	Mass retained (g)	% retained	Cumulative % retained	Cumulative % finer
1	4.75	4.75 mm	70	7	7	93
2	2	2 mm	14	1.4	8.4	91.6
3	1	1 mm	134.5	13.45	21.85	78.15
4	0.60	0.6 mm	51.9	5.19	27.04	72.96
5	0.425	0.425 mm	126	12.6	39.64	60.36
6	0.3	0.3 mm	154.4	15.44	55.08	44.92
7	0.212	0.212 mm	157.5	15.75	70.83	29.17
8	0.15	0.15 mm	114	11.4	82.23	17.77
9	0.075	0.075 mm	156	15.6	97.83	2.17
10	pan	pan	17.53	1.75	99.58	0.42

APPENDIX III

Determination of coefficient of permeability

Details	Soil Sample
Hydraulic head(cm)	35
Length of soil sample (cm)	12
Cross sectional area of sample (cm^2)	78.5
Time interval (sec)	50
Quantity of flow (cm^3)	20000
coefficient of permeability (cm / sec)	1.74

APPENDIX IV

Annual rainfall data of the study area

Sl No	Year	Rainfall(mm)
1	2000	2179
2	2001	2400.1
3	2002	2303.6
4	2003	2223
5	2004	2895.2
6	2005	2663.1
7	2006	3460.5
8	2007	3992.8
9	2008	2403.7
10	2009	2883.3
11	2010	3018.4
12	2011	3465.3
13	2012	2170.4
14	2013	3264.5
15	2014	2756.8
16	2015	2639.4

DESIGN AND EVALUATION OF A HORIZONTAL FILTER UNIT FOR GROUND WATER RECHARGE THROUGH ABANDONED TUBE WELL

by

JOMOL T JOSEPH

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ABSTRACT OF THE THESIS

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TAVANUR, MALAPPURAM -679573

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ABSTRACT

The groundwater table is declining at an alarming rate and it is essential to replenish the dried out aquifers by adopting proper artificial recharge methods. Field experiment on the design and evaluation of a horizontal filter unit for groundwater recharge through abandoned tube well was conducted in the research field of Nodal Water Technology Centre, College of Horticulture, Vellanikkara. The specific objectives of the study were to design and develop a horizontal filter unit with alternate filter media for treating storm water runoff, and to evaluate the developed filter for hydraulic and pollutant removal efficiencies. Suitability of the tube well for recharging and availability of adequate amount of source water were analysed in the primary stages of study. The peak runoff expected from the area was computed and compared with the carrying capacity of the existing conveyance channel. Thus the existing channel was modified and a masonry structure with a filter unit for treating runoff and a recharging section was constructed. The filter unit had five compartments filled with Gravel, Sand, Charcoal, Synthetic fibre and Coir fibre combinations as treatments, T1: Gravel, Sand, Coir fibre, Gravel; T2: Gravel, Sand, Synthetic fibre, Gravel; T3: Gravel, Charcoal, Sand and Gravel. Three sets of length variation in three different media combinations were selected as factors, F1: 80 cm, 80 cm, 80 cm, 80 cm; F2: 80 cm, 100 cm, 60 cm, 80 cm; F3: 80 cm, 60 cm, 100 cm, 80 cm

Inflow and outflow water quality was analysed for evaluating filter hydraulic and pollutant removal efficiencies in simulated and actual runoff conditions. Treatment T1F1 was better in pH normalising efficiency, T1F2 removed Nitrate and Sulphates effectively, T1F3 was better in Total hardness and Calcium removal efficiency, T2F1 performed well for Magnesium and Chloride removal efficiencies. Treatments T2F2 and T3F3 were effective for EC, TDS, Salinity, TSS, Turbidity, Acidity, Fluoride, Alkalinity, Iron removal and Hydraulic efficiencies.

The Gravel (80 cm), Charcoal (100 cm), Sand (60 cm) and Gravel (80 cm) combination was selected as best filter media combination and it was installed in the field for recharging. With an average annual rainfall of 2795 mm in the study area, a runoff depth of 1118 mm can be expected. Accordingly a runoff volume of 2.3 million litres of water can be diverted from the study area to the recharge well annually. Comparison of this enormous benefit from the artificial recharge structure with the cost incurred is indicating the promising future of the artificial recharge schemes. If the abandoned open wells and tube wells in Kerala are utilised as recharge wells, a large quantity of water can be recharged annually and it will improve the groundwater potential of the state for future benefits.

സംഗ്രഹം

ഭൂഗർഭജല നിരപ്പ് ക്രമാതീതമായ തോതിൽ താഴ്ന്നു പോകുന്നത് നിയന്ത്രിക്കുവാൻ കൃത്രിമഭൂജലപോഷണമാർഗങ്ങൾ ഉപയോഗപ്പെടുത്തി ഉണങ്ങിപ്പോയ ഭൂഗർഭജലസ്രോതസ്സുകളെ പുനർജീവിപ്പിക്കേണ്ടത് അത്യാവശ്യമാണ്. നോഡൽവാട്ടർടെക്നോളജിസെന്ററ്, CoH ന്റെ റിസേർച്ച് ഫീൽഡിലെ ഉപേക്ഷിക്കപ്പെട്ട ട്യൂബെൽ വഴി കൃത്രിമഭൂജലപോഷണം നടത്തുന്നതിനും അതിനു അനുയോജ്യമായ ഒരു തിരശ്ചീന അരിപ്പയൂണിറ്റ് ഡിസൈൻ ചെയ്ത് അതിന്റെ പ്രവർത്തനം വിലയിരുത്തുകയും ആണ് ഈ ഫീൽഡ്പരീക്ഷണത്തിൽ നടത്തിയത്. പഠനത്തിന്റെ പ്രഥമ ലക്ഷ്യങ്ങൾ ഫിൽട്ടർ ഫലപ്രദമായി രൂപകല്പനചെയ്ത് വികസിപ്പിക്കുകയും കാര്യക്ഷമമായി വികസിപ്പിച്ച ഫിൽട്ടർ വഴി ശുദ്ധീകരിച്ച വെള്ളം റീച്ചാര്ജ് ചെയുക എന്നതും ആയിരുന്നു. റീചാർജ്ജ് ചെയേണ്ട വെള്ളം മതിയായ അളവിൽ ലഭ്യമാണോ എന്നും റീച്ചാര്ജിംഗിന് ട്യൂബ് വെൽ അനുയോജ്യമാകുമോ എന്നും പഠനത്തിന്റെ പ്രാഥമികഘട്ടങ്ങളിൽ വിശകലനത്തിനു വിധേയമാക്കി. പ്രദേശത്ത്നിന്ന് പ്രതീക്ഷിക്കുന്ന ഒഴുകുവെള്ളത്തിന്റെയും നിലവിലെ ചാനൽ കപാസിറ്റിയും തട്ടിച്ചുനോക്കിയതിനുശേഷം നിലവിലുള്ള ചാനലിൽ ഒരു റീച്ചാർജ്യൂണിറ്റും ഫിൽട്ടർയൂണിറ്റും ചേർന്ന ഘടന നിർമ്മിച്ചു. ഫിൽട്ടർയൂണിറ്റിൽ ചരൽ, മണൽ, ചാർക്കോൾ, സിന്തറ്റിക്ഫൈബർ, കയർഫൈബർ എന്നിവ നിറച്ച് പരീക്ഷണം നടത്തി. മൂന്നു വ്യത്യസ്ത മീഡിയകോമ്പിനേഷനുകളും ദൂരംവ്യതിയാനങ്ങളുടെ മൂന്ന്സെറ്റ് പരീക്ഷണാത്മകപരിശോധനക്കായി ആയി തിരഞ്ഞെടുത്തു. ഫിൽട്ടർ ചെയ്ത് വന്ന ജലത്തിന്റെ ഗുണനിലവാരവും ഫിൽട്ടർ ചെയ്ന്ന നിരക്കും പരിശോധിച്ചു. അവയിൽ നിന്നും ചരൽ (80 സെ.മീ), ചാർക്കോൾ (100 സെ.മീ), മണൽ (60 സെ.മീ), ചരൽ (80 സെ.മീ) എന്ന കോമ്പിനേഷൻ മികച്ചതായി കണ്ടെത്തി അത് ഫിൽട്ടർ മീഡിയ കോമ്പിനേഷനാക്കി ഇൻസ്റ്റോൾചെയ്തു. പഠനംപ്രദേശത്തെ 2795 മില്ലീമീറ്റർ ശരാശരി വാർഷിക മഴയിൽ നിന്നും, 1118 മില്ലീമീറ്റർ ഒഴുക്കുവെള്ളം പ്രതീക്ഷിക്കാം. അതനുസരിച് എകദേശം 2.3 മില്യൺലിറ്റർ വെള്ളം പ്രതിവർഷം റീചാർജ്ചെയാന് കഴിയും. ചെലവ് കുറഞ്ഞ കൃത്രിമറീചാർജ് പദ്ധതികളുടെ ഭാവിയാണ് ഇവ സൂചിപ്പിക്കുന്നത്. കേരളത്തിൽ ഉപേക്ഷിക്കപ്പെട്ട കിണറുകളെല്ലാം റീചാർജ്ജ് യൂണിറ്റുകളാക്കി മാറ്റിയാൽ നമ്മുടെ സംസ്ഥാനത്തിന്റെ ഭാവി ഭൂഗർഭസാധ്യതകൾ മെച്ചപ്പെടും.