IMPROVEMENT OF PURIFICATION SYSTEM FOR ROOF WATER HARVESTING

by

SWATHA,V.S.

(2013 – 18 – 107)

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA

2015

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THESIS

Submitted in partial fulfilment of the

requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR - 679573, MALAPPURAM
KERALA
2015

DECLARATION

I hereby declare that this thesis entitled **"Improvement of purification system for roof water harvesting"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **“Improvement of purification system for roof water harvesting”** is a record of research work done independently by **Mrs. Swatha,V.S (2013 – 18 – 107)** 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.

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ACKNOWLEDGEMENT

With deep sense of gratitude, indebtedness and due respect, I express my heartfelt thanks to my advisor ***Dr. Sathian, K.K.****, Associate Professor, Department of Land and Water Resources and Conservation Engineering, KCAET, Tavanur for his valuable guidance, criticism and immense help throughout the course of work. His critical suggestions and comments was undoubtedly been the key for the successful preparation of this thesis work.*

Words seem to be inadequate to express my sincere thanks to ***Dr. M. Sivaswami****, Former Dean, KCAET, Tavanur for his professional guidance and constructive suggestions offered during this study. I express my heartfelt thanks to* ***Dr. Hajilal M.S****, Dean, KCAET, Faculty of Agricultural Engineering and Technology for the unfailing guidance and support that he offered while carrying out the project work.*

I express my heartfelt thanks to ***Dr. Abdhul Hakkim, V.M****, Associate Professor and Head, Department of Land and Water Resources and Conservation Engineering, KCAET, Tavanur for the valuable advices, encouragement, sincere help and co-operation towards me for the evaluation of my thesis.*

I engrave my deep sense of gratitude to ***Dr. Sasikala, D****., Associate Professor and Head, Department of Irrigation and Drainage Engineering, KCAET, Tavanur for her valuable suggestions, evaluation and due encouragement during the entire period of the project work.*

I express my deep sense of gratitude and indebtedness to ***Er.Vishnu, B****., Assistant Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanur. I am thankful for his advices, creation of immense interest in the subject and profound encouragement during every phase of my thesis work*

I sincerely acknowledge the help and suggestions of ***Dr. Rema, K.P****., Associate Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanur, during my thesis work.*

I express my thanks to ***Mr. Sreekumaran, S.****, Assistant Librarian, and all other* ***staff members of Library****, KCAET, Tavanur for their ever willing help and cooperation.*

With great pleasure I express my heartfelt thanks to all teachers of KCAET Tavanur for their support during my thesis work.

I express my whole hearted floral thanks to Technicians in KCAET, Mohammedkutti,T, Mansoor, Unnikrishnan, who helped us a lot in our work.

With great pleasure I express my heartfelt special thanks to my batchmates for their enthusiastic cooperation from time to time for each step of my thesis work.

I am greatly indebted to my parents, husband and brother for their blessings, prayers and support without which I could not have completed this work.

I express my sincere gratitude to KAU for providing opportunity for post graduation.

My thanks remain with all those who have helped me in one way or other for the completion of the research work.

Above all, I thank The Almighty for his blessings which helped me in the completion of this work.

Swatha, V.S.

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SYMBOLS AND ABBREVIATIONS

mm	-	millimeter
cm	-	centimeter
m	-	metre
m^2	-	square metre
m^3	-	cubic metre
km	-	kilometre
µ	-	micron
mg	-	milligram
Kg	-	kilogram
ml	-	millilitre
l	-	litre
min	-	minute
MCM	-	million cubic meter
SW	-	south west
NE	-	north east
et al	-	and others
KAU	-	Kerala Agricultural University
RCC	-	Reinforced Cement Concrete
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
Dt	-	District
GIS	-	Geographical Information System
RRWH	-	Rooftop Rain Water Harvesting

RWH - Rain Water Harvesting

RTL - Radio Tracer Lab

BIS - Bureau of Indian Standards

PVC - Poly Vinyl Chloride

GI - Galvanized Iron

TDS - Total Dissolved Solids

TSS - Total Suspended Solids

EC - Electrical Conductivity

TH - Total Hardness

COD - Chemical Oxygen Demand

ADWG - Australian Drinking Water Guideline

MTA - Male Thread Adaptor

dS/m - deci Siemens per meter

ppm - parts per million

Fig - Figure

conc - concentration

IS - International Standards

WHO - World Health Organization

No. - Number

INTRODUCTION

CHAPTER 1

INTRODUCTION

Existence of all forms of life depends upon the availability of water. Water shortage which experiences in almost all geographical locations and its increasing severity is of great concern and is being debated among all water resources scientists or hydrologists. The severity of the situations can be conceived from the fact that presently space scientists are vigorously engaged in searching for water on other planets.

According to the United Nations Environment Programme (UNEP), more than 2000 million people would live under conditions of high water stress by the year 2050. This message warns us that water could prove to be a limiting factor for development in a number of regions in the world. About one-fifth of the world's population lacks access to safe drinking water and with the present consumption patterns; two out of every three persons on the earth would live in water stressed conditions by 2025.

According to the UNEP report, pollution and scarcity of water resources and climate change would be the major emerging issues in the next century. Providing access to safe drinking water would be the most effective means to improve public health. It is clear that all possible approaches must be tried to mitigate the problem of shortage in drinking water by exploring simple and low cost house hold interventions. In spite of higher average annual rainfall in India (1,170 mm) as compared to the global average (800 mm), it experiences water scarcity of different orders. The projections of India becoming a water stressed country by 2025 will be a reality if no substantial measures are taken to conserve rain and surface water. It is in this context, that rainwater harvesting gain importance. Rain captured from 1-2% of India's land could provide India's population of 950 million with as much as 100 litres of water per person per day (Agarwal, 1998). There is no village in India which could not meet its drinking water needs through rainwater harvesting as there is a synergy between population density and impervious catchments to harvest rainfall. And in populated areas there are usually more impervious surfaces like rooftops, roads, etc. which have improved runoff coefficient.

Rain water harvesting means capturing the rain from where it falls. There are a variety of ways of harvesting rain water, such as capturing runoff from rooftop, local catchments, capturing seasonal flood waters from local streams and conserving water through watershed management. Rainwater harvesting is often considered to be traditional method of water collection and storage. The practice of rainwater harvesting can be traced back to many centuries back, especially in a country like India where rainwater harvesting is mentioned in ancient inscriptions. Types and methods of rainwater harvesting have changed over time, and many different systems are now available all over the world. After a relatively long period in dormant state, domestic rainwater harvesting has again started making impact in many countries (especially in the developing world) as an alternative household water supply option. A number of reasons can be attributed to this resurgence, the more important ones are (1) decrease in the quantity and quality of both ground water and surface water, (2) failure of many piped water schemes due to poor operation and maintenance, (3) improvement in roofing material from thatched to more impervious materials like concrete, tiles, corrugated iron sheets and asbestos, (4) increased availability of low cost rainwater harvesting techniques, (5) shift from more centralized to decentralized management and development of water resources, and (6) increase in competition between different sections of the society and the global trend towards rural to urban migration.

During the past two decades, many developments in rainwater harvesting have taken place both in the developed and developing countries. A sizable population of the world has relied upon rainwater harvesting to supply water to meet various needs such as drinking, irrigation etc. Rainwater harvesting promotes self sufficiency and fosters the concept of water conservation. It saves money, saves other sources of water, reduces erosion and storm water runoff and increases water quality. Rainwater can provide clean, safe and reliable water for drinking so long as the collection and purification system are properly designed, constructed and maintained for its intended use. Rainwater harvesting means capturing rain where it falls or capturing the runoff in a village or town and taking all precautions to keep it unpolluted. One third of world's population is experiencing severe water scarcity right now. In rural areas, the water may not be fit for drinking due to the polluted water bodies, due to contaminated ground water and also due to acute water scarcity. In urban areas, water demand increases due to increase in the population. In the situations, the most effective way to obtain fresh drinking water is to harvest rainwater.

The state of Kerala has enough potential to tap rain water to solve its water scarcity especially the domestic and small irrigation needs as the availability of water during the two monsoon seasons viz. south west & north east is very high (about 250 cm). Rainwater harvesting system is inherently simple in form, and can often be assembled with readily available materials with a basic understanding of the plumbing and construction skills. Commonly available rooftop rainwater harvesting system meant for house hold purposes have one deficiency, ie their filter system cannot be cleaned easily. In Kerala, with humid tropic climate, it is found that the major impurities coming from rooftop is moss which is getting dislodged during rainfall. Filter system used in the present roof water harvesting systems include sand and gravel media. These filters get clogged very easily by the moss and other organic matter. This prevents the flow of water through the media, and the moss start decaying, giving rise to very bad odour. Because of this problem, most of the roof water harvesting systems installed for institutions and on community basis are unused and abandoned.

The quality of harvested rainwater depends upon many factors such as air quality, system design and maintenance, materials used, rainfall intensity, length of time between rainfall events, and type of the catchment. Due to rapid economic development and industrializations, concerns about air pollution is on the rise in RWH in developed and developing nations. Rainwater collects particulate and dissolved solids from the atmosphere and pollutes itself. The scavenging of the atmospheric pollutants affects the chemical composition and the pH of the rainwater. It is reported that the raindrops immediately coming out of the cloud possess relatively low pH, but when they reach the earth's surface, the pH is increased. During the last decade, a number of studies on the chemical composition of precipitation have been carried out in parts of North India. Studies regarding the investigation of atmospheric deposition have not been reported from Kerala.

After air, the next important source of rain water pollution is roof catchment from where it is collected. Shijila and Sathian, 2014 have reported that the most important impurity to be removed from roof top rain water is the organic impurities such as mosses and other small vegetation. The study also brought to light that the impurities present on roof top depend on the type of roofing material. Micro mesh filters have proved to be an alternative to sand and gravel media filter. They are very easy to clean besides having good cleaning efficiency (Shijila and Sathian, 2014). At the same time, micromesh filters require further modifications and improvisations to make it more efficient and user friendly.

In this context, this study has been carried out to design and develop more efficient and hassle free filter system for domestic roof water harvesting with the following specific objectives:

- To develop an appropriate first flush system for domestic roof water harvesting.
- To develop an efficient filter system for roof water harvesting.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Water harvesting is concerned with a broad range of activities and it encompasses a wide range of actions including rainwater collection from rooftop and surface runoff catchment, rainwater storage in small tanks and large-scale artificial reservoirs, groundwater recharge, and also protection of water sources against pollution. Archaeological evidences have shown that the history of different water harvesting techniques dates back to 4000 to 6000 BC in India and China. The objective of water harvesting in developing nations differs for urban and rural areas. In urban areas, emphasis is on managing storm water and increasing groundwater. On the other hand, in rural areas, the emphasis is to provide water for drinking and farming, especially for life-saving irrigation. Catchments used in water harvesting include rooftops, roads and other impervious manmade structures, rocky surface, hill slopes or artificially prepared impervious/semi-pervious land surface. The amount of water harvested depends on the intensity, duration and frequency of rainfall, catchment characteristics and water demands. Literature review presented in this chapter focus on rain water harvesting, rooftop rain water harvesting, components of rooftop rain water harvesting, purification of rooftop rain water and drinking water quality standards.

2.1 Rain water harvesting

Rainwater harvesting is the collection, accumulation and storage of rainwater for domestic use, irrigation, livestock and other small scale water needs. In many places, the water collected is directed to pits and trenches for percolation. Several research and other reports have described the immense potential of rain water harvesting in solving the seasonal water scarcity in all parts of the world. Another notable feature of rain water is that it is soft and is free of most physical, chemical and biological impurities. Benefits of rainwater harvesting may be grouped as given below.

Benefits of rain water harvesting system:

- It is free and comparatively clean source of water. Cost is involved for collection and storage.
- It is very ideal to solve summer domestic water scarcity in humid tropics as every house hold can afford to have one unit of roof water harvesting structure.
- It can facilitate as an excellent back up source in emergencies for places serviced by water supply.
- It is most environment friendly and is socially acceptable if provided with good cleaning system.
- Technology used is not expensive and easy to maintain by the user.
- It substantially reduces the suitability of urban water drainage and thus minimizes the capacity requirement of the system leading to great economy and easing of difficulties associated with its disposal.
- Reduces sheet flows and concentrated surface runoff and brings down the top soil loss, a measure very much warranted for the productivity of agricultural land and reservoir sedimentation.
- It is an ideal measure for groundwater recharge to maintain ground water balance and sustainability.

Kadirvelu *et al*. (2002) described the impact assessment of RWH in Madras University-Marina campus. RWH structures were designed on the basis of the insitu soil conditions. The frequent monitoring of water levels of three open wells was done. The water levels during the pumping before and after the implementation of RWH were monitored. The water levels and the water quality were compared with the observation wells situated outside the study area and maintained by TWAD. The benefit cost ratio was also worked out considering the construction cost of RWH and the population to be served by the harvested rain. Finally, the study concludes that the quantity and quality of groundwater has been improved. The benefit cost ratio obtained was 2.38. Hence, the impact of RWH and recharge was positive in the study area in view of improved water quantity, quality and benefit cost ratio.

The impact assessment of RWH (Rainwater harvesting) on ground water quality was studied by Deepak Khare *et al*. (2004) at Indore and Dewas, India. The study reports that the recharge of ground water with roof harvested rainwater improve both quantity and quality of ground water. In this, the roof top rainwater was directed into the ground using sand filter as a pretreatment system. This leads to a reduction in the concentration of pollutants in ground water which indicated the effectiveness of increased recharge of aquifer by roof top rain water. The author reports that in certain areas, the amount of total and fecal coliform were observed high in harvested tube well water than normal tube well water. The reason of this increase was the poor cleanliness of roof top and poor efficiency of filter for bacterial removal. The work concludes that quality monitoring of rainwater harvesting is an essential prerequisite before using it for ground water recharge.

Shukla and Mangesh (2006) designed a simple and cheapest model of rainwater harvesting keeping in mind the amount of precipitation, topography, soil depth, vegetation, cost of construction, and storage and distribution system for the poor people of northeast India. The study reports that, rainfall is the main source of surface water and its conservation is essential. Also, rainwater harvesting is one of the most promising techniques for collection of excess runoff. In north eastern part of India, bamboo is considered as the green gold. From storage to groundwater recharge for the model developed, bamboo has been used, which is easily available locally. It is reported that this technique of rainwater harvesting would be very cheap for the farmers in particular and the masses in general residing the hilly regions as well as in the plains of northeast India.

A study was conducted by Jebamalar and Ravikumar (2011) on comparative analysis of hydrologic responses to rainwater harvesting in two hydrologically different locations of Chennai city, India. This paper attempts to investigate the implementation of rainwater harvesting (RWH) structures and its hydrologic responses. The study reported that design of RWH structures is site specific as it involves hydrometeorology, lithology and land use. Consequently, its effectiveness depends on appropriate design and implementation. A questionnaire based survey has been conducted to collect details of implemented RWH structures and analysed. Impact of RWH for possible recharge was assessed using GEC NORMS 1997 by water level fluctuation method. Water samples were analysed for different quality parameters and it is found that the recharge and quality have improved due to the implementation of RWH.

Chowdhury (2012) has carried out a research on the feasibility study of rainwater harvesting system in Sylhet City, Bangladesh. This study focuses on the possibility of harvesting rainwater in rural communities and thickly populated urban areas of Sylhet. The study reported that presences of arsenic in underground water possess a serious threat to the success once made in water supply. Harvesting rainwater and its recharge has been cited as a pragmatic solution to this problem.

2.2 Rooftop Rainwater Harvesting

Rooftop Rain Water Harvesting is the technique through which rain water is captured from the roof catchments and stored in small to medium sized tanks.Surplus after storing to the full capacity of the storage tank can be allowed for ground water recharge. The Main Objective of rooftop rain water harvesting is to make water available during dry season. Capturing and storing rain water from roof is particularly important in dry land, hilly, coastal and urban areas.

As the rooftop is the main catchment, the quantity and quality of rain water collected depends on the area and type of roofing material. Reasonably pure rain water can be collected from roofs constructed with RCC slab, galvanized corrugated iron, aluminium or asbestos cement sheet, tiles and thatched roofs. Roof catchments should be cleaned regularly to remove dust, leaves and bird droppings so as to maintain the quality of water. The amount of water that is received in the form of rainfall over an area is called the rain water endowment of that area. Out of this, the amount that can be effectively harvested is called the water harvesting potential. The runoff coefficients in the case of roofs vary from 0.7 to 0.9 with the type of roofing materials.

Jyothison *et al.* (2002) conducted a study on the assessment of roof water harvesting potential and recharge pit design in KCAET Tavanur. They found out the infiltration and seepage rate and also conducted the permeability tests. They determined the size of recharge pit for different roofs in KCAET from the results obtained.

Visalakshi *et al.* (2006), developed rainwater harvester in KAU, Thrissur, as a safeguard against water crisis of the campus. The following rainwater harvesting structures were made to mitigate the water scarcity problems of the Ladies Hostel of College of Horticulture, Vellanikkara. The excess flow of 2341 m^3 is utilized for ground water recharge by providing gravel packed percolation pits of size 2 m diameter, with 2 m depth.

Sharma (2007) has carried out a roof water harvesting study at Delhi and has reported that the water supply of the city is under tremendous stress due to the over exploitation of ground water as a result, the water table was declining at an alarming rate. However, Delhi is blessed with an average annual rainfall of about 100 cm, and the response of abundant building structures and Group Housing creates huge roof water potential. A dwelling unit with a roof top area of 150 m^2 in a total land area of 900 m^2 in Kishangarh in East Delhi, where six adult persons reside was selected for the implementation of the scheme of roof-top rain water conservation. It has been found that rainwater harvesting is the most appropriate method for augmenting groundwater level artificially in the area where natural recharge is considerably reduced due to increased urban activities and not much of land is available for implementing any other artificial recharge measures.

Rishab *et al.* (2007) presented a paper on use of water harvesting as an effective tool for water management. The various forms of water harvesting have been elucidated. The common goal of all forms was to secure water supply for annual crops, pastures, trees and animals in dry areas without tapping groundwater or river-water sources. As the appropriate choice of technique depends on the amount of rainfall and its distribution, land topography, soil type and soil depth and local socio-economic factors, these systems, it is reported, tend to be very site specific. The water harvesting methods applied strongly depend on local conditions and include such widely differing practices as bunding, pitting, micro catchments water harvesting, flood water and ground water harvesting.

Arun and Sudhir (2009) have presented a paper based on the analysis of survey record of around 50 houses with different rooftop areas of peri-urban area of Dhule city in India. The estimation of the appropriate size of the storage tanks and their costs required to fulfill the annual drinking water demands through Domestic Rooftop Water Harvesting (DRWH) were done. A mathematical equation expressing the relationship between the required size of water tank and different rooftop areas is developed. The DRWH systems for all houses have been designed considering the existing rain water outlets and cost estimation for each individual house. They have developed a cost model expressing the relationship between rooftop area and cost of DRWH system.

A study on roof rainwater harvesting systems for household water supply in Jordan has been reported by Fayez and Shareef (2009). The objectives of this study were to evaluate the potential for potable water savings by using rainwater in residential sectors of the 12 Jordanian governorates and provide suggestions and recommendations regarding the improvement of both quality and quantity of harvested rainwater. Results showed that a maximum of 15.5 mm^3/y of rainwater can be collected from roofs of residential buildings provided that all roof surfaces are used and all rain falling on the surfaces is collected. This is equivalent to 5.6pecentageof the total domestic water supply of the year 2005. The potential of potable water savings was estimated for the 12 governorates, and it ranged from 0.27 percentage to 19.7 percentage. Analysis of roof water samples indicated that the presence of inorganic compounds generally matched the WHO standards for drinking water. On the other hand, fecal coliform, which is an important bacteriological parameter, exceeded the limits for drinking water.

Harishankar *et al.* (2010), did a project on improved design of RRWH in KCAET Tavanur, Malappuram. An upward flow type filter, having alternate layers of coir fiber and activated charcoal filled in a PVC pipe to a density of 83.65 kg/m^3 was installed. The filtration rate and efficiency of the filter were found to be 3.83 m^3/min and 90percentage respectively. The study concluded that the improved design was more efficient.

Constantin *et al*. (2010) developed a system of rainwater collection, storage and pumping. The technical system of rainwater collection, storage and pumping for drip irrigation was tested in the greenhouses belonging to the Research and Development Station for Vegetable Growing of Buzau within the Academy of Agricultural and Forest Sciences of Bucharest. The experimental design included a network of water collecting pipes on the roof of the greenhouse, a water storage basin and a water pumping unit.

Andrew *et al*. (2010) through the research paper, searches for alternative water resources for rural residential development by adopting roof water and grey water in residential envelope as per Australian water standards. The results showed the benefits of grey water recycling, which contributes to greater saving of main water supply than rainwater use, and which reduces more than half of the wastewater to receiving waters in the rural township of Cranbrook, Western Australia. The result of this study reveals that grey water usage more significantly reduces the demand of general water supply than of rainwater harvesting.

Beckman *et al.* (2011) of National Research Development Corporation (NRDC) have published a research work on capturing rainwater from rooftops at different places of United States. The study evaluated the available daily rainfall and conservatively estimated non-potable water demands that could be replaced by using rainwater for eight selected U.S. cities. GIS techniques were used to determine the available amount of rooftop rainwater that could be captured in each of the cities.

Singh *et al*. (2011) made a design and a cost estimation procedure for rainwater harvesting system for the roofs of buildings at College of Technology, GBPUAT, Pantnagar, Uttarakhand. Past rainfall data of 49 years was analyzed to determine the probability of occurrence. The study recommend that one surface tank of 81 m^3 (6 m × 6 m × 2.25 m) size each for four hostels and four surface tank of 100 m^3 (8 m × 5 m × 2.5 m) size were required for college buildings.

Vilane (2011) presented a study as the inventory of rainwater harvesting technologies in Swaziland. The water stored per household ranged from 100 *l*, to 1,000 *l*. It was concluded that there is potential for increasing water harvesting in the regions where it is practiced.

An improved design of a simplified rooftop rainwater filtering system was developed by Hameeda et al. (2013) at KCAET, Tavanur, Malappuram, Kerala. The design includes the construction of an upward flow mesh filter of 100 micron size. The unique feature of the system was its ease of cleaning. The filter performed very effectively in the removal of suspended particles.

Hajaniand Rahman (2014) carried out a study on rainwater utilization from roof catchments in arid regions in Sydney city, Australia. This paper examined the feasibility of rainwater harvesting from roof catchments in arid regions of Australia. For this, ten representative locations in the arid regions of Australia were selected. Also, ten different sizes of rainwater tanks ranging from 5 m^3 to 50 m^3 and three different combinations of water uses were considered. A model was developed to simulate the performance of rainwater harvesting (RWH) system. It was found that the reliability of a RWH system is highly dependent on mean annual rainfall at the location of interest. It was found that a 20 m^3 tank could provide a reliability of 61percentage to 97 percentage for toilet and laundry use depending on the location within the Australian arid regions. The study reported that, at the prevailing water price, RWH system is not financially viable in the Australian arid regions. The methodology adopted in this paper can be adapted to other similar arid regions of the world.

2.3 Components of rooftop rainwater harvesting system

A roof top rainwater harvesting system comprises various stages such as collection of roof water, transporting water through pipes or drains, filtration, and storage in tanks for reuse or recharge. The common components of a rainwater harvesting system involved in these stages are described here.

2.3.1 Catchment

For household or domestic RRWH, the roof of the building is generally used as the catchment area. Some materials used to coat the roof such as bitumen, paints or sheeting containing lead, may pose risk to human health. RWH systems are best-suited where the roofing material is smooth and coated with chemically neutral substances. Non-corrosive sheet metals such as galvanized sheets or alloy of aluminium are ideally suited for use with RWH systems (Narasimha *et al.*,2011). They are less prone to build-up and contamination from dust, leaves, animal droppings and other debris, compared to rougher roof surfaces such as tile, asbestos or thatch.

2.3.2 Gutter

Gutters, downspouts, and piping are used to collect and transport the roof water and convey it to the tanks that will store it prior to treatment. Gutter should gradually (but continuously) slope toward the downspout. Otherwise, it will not drain completely and algae and bacteria will begin to grow in the water that remains after the rainfall event. For best efficiency, the gutter should have about 1 percentage slope. If roof tends to capture leaves, twigs, or other large debris, it is mandatory to install a leaf guard, gutter screen, or other similar material on the top of gutter. The leaf guard should flush the debris away from the gutter rather than trapping the material directly above it.

The size of the gutter should be according to the flow rate during the highest intensity rain. It is advisable to make them 10 to 15 per cent oversize. Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house. It is possible to fix iron or timber brackets into the walls, but for houses having wider eaves, some method of attachment to the rafters is necessary (Luke, 2005).

2.3.3 First flushing or foul flushing

Roof based collectors are less susceptible to chemical and biological contamination than land based collectors. Nevertheless, even well designed roofs will collect some contaminants during the periods between two rainfall events. Although a leaf guard or gutter screen can keep large debris out of your system, a first flush diverter is needed to keep most of the dust, dirt, chemical contaminants, or animal and bird droppings out of the untreated water storage tank. Most of these contaminants will be rinsed off the roof during the first few minutes of a major rainfall event. In order to prevent them from reaching your storage tank, a first flush diverter is to be installed on each downspout that discharges to the tank. First flush diversion is increasingly recognized as a useful intervention to reduce both suspended and dissolved contaminate loads in rooftop rainwater systems. Such first flush systems rely on the early rain to wash the roof before water is allowed in the store. While there is almost universal acceptance that this is beneficial, there is no agreement on just how much water is to be diverted (Martinson *et al.*2009).

Doyle and Peter (2010) studied the impact of first flush removal on rainwater quality and rainwater harvesting systems reliability in rural areas of Bisate Village, Rwanda. In this study, after a rain event, the samples were tested for a variety of water quality parameters, including turbidity. The simulations showed that for these systems the reliability of water availability would be reduced by less than 50 percentage with diversion of the recommended first flush. Diversion of the first flush was found to reduce the reliability by at most 8 percentage. Analysis of three existing RWH systems indicated that a recommended 1 mm first flush diversion or foul flush would reduce the number of days the system meets demand by no more than 7 days per year.

For the evaluation of the performance of first flush, Kus *et al.* (2010) conducted a study on the water quality in rainwater storage tanks. The main aim of the study was to develop a cost effective in line filtration. One component of this evaluation was to observe the effects of the first flush on the quality of rainwater storage. The results showed that bypassing the first 2 mm of rainfall gives water with most water quality parameters compliant with the Australian Drinking Water Guidelines (ADWG) standards.

Georgios *et al*. (2012) conducted a study on assessment of water quality of first flush roof runoff and rainwater stored in storage tanks. In this study, six pilot rainwater harvesting systems were installed in five urban, suburban and rural houses, and on an institutional campus. The systems consisted of horizontal gutters to collect roof drainage, and down drains which end into one or two plastic storage tanks. Devices were also provided to remove first flush water. Water quality was monitored in the storage tanks and the first flush devices during the 2 year period from October 2006 to November 2008. Water samples were collected at a frequency of once every 10 days, and analyzed according to potable water specifications to determine major total suspended solids, alkalinity, total phosphorus and microbiological indicators. Furthermore, temperature, pH, dissolved oxygen and electrical conductivity were measured in situ. The collected rainwater quality was found satisfactory with regard to its physicochemical parameters, but not in the case of sanitary. Therefore, rainwater harvesting systems in that area could only supply water appropriate for use as gray water.

2.3.4 Filter system

The filter unit is a container or chamber filled with filter media such as coarse sand, charcoal, coconut fiber, pebbles and gravels to remove the debris and dirt from water that enters the tank. The container is provided with a perforated bottom to allow the passage of water. The filter unit is placed over the storage tank. Commonly used filters are of two types. One is a ferro-cement filter unit, which is comparatively heavy and the other is made of either aluminium or plastic bucket. The latter is readily available in market and has the advantage of ease in removing, cleaning and replacing. Another simple way of filtering the debris and dust particles that came from the roof along with rainwater is to use a fine cloth as filter media. The cloth, in two or three layers, can be tied to the top of a bucket or vessel with perforations at the bottom. Filter units consists of a chamber filled with filtering media such as fibre, coarse sand and gravel layers to remove debris and dirt from water before it enters the storage tank or recharge structure (John, 2011). Filters are used for treatment of water to effectively remove turbidity, colour and microorganisms. After first flushing of rainfall, water should pass through filters. There are different types of filters in practice, and commonly used filters are sand, charcoal and mesh filters.

Sangho *et al.* (2007) carried out a study on reuse of grey water and rainwater using fiber filter media and metal membrane in Korea. In this study, novel treatment options including lignocellulose filter media and metal membranes were examined to reuse grey water and rainwater in office buildings. Laboratory scale experiments were performed to evaluate the potential of these technologies. The fiber filter media was useful to control first flush rainwater but was not enough to produce water for non-potable use in buildings. Thus, the metal membrane filtration was attempted to reject particulate pollutants. The removal efficiency of various pollutants and the membrane permeability were examined using metal membranes with different pore sizes.

In 2011, roof water harvesting structure and slow sand filters (SSF) were developed by Khadse *et al.* (2009). The SSF was constructed and commissioned at village Chaati, Himalaya. The construction of filter was made using local material including sand media. The capacity of SSF plant was 9 m^3/d. It is worth mentioning that this water treatment technology was devoid of any power requirement. The study showed that the filter did not produce toxic inorganic chemical waste and require only less frequent maintenance and also it was found that filter functioned with the aid of gravity and naturally occurring microbiological life, much in the same way that water is purified by a wetland near a deep sandy riverbank.

A research work on water purification using magnetic was reported by Ritu and Mika (2010). With the increase in demand, from several sectors the supply needs to meet specific standards. Several purification techniques have been adopted to meet the standards. Magnetic separation is one purification technique that has been adapted from ore mining industries to anti-scale treatment of pipe lines to seeding magnetic flocculent. This study explained large volume of information on this water purification technique and explains different aspects of magnetism and magnetic materials for water purification.

A slow sand filtration for rainwater treatment in airports followed by chlorination was demonstrated by Ronan *et al*. (2012) and they calculated filtration efficiency and economic costs. The objectives of this research were to assess rainwater quality in an airport environment and to study the performance of slow sand filtration followed by chlorination in the treatment of rainwater and analyze treatment costs. The study was carried out in a mid-size airport in Brazil. The proposed system provided water with physical, chemical and microbiological quality consistent with recommendations for reuse and the price per treated cubic meter was 60% lower than the price paid to the existing water supplier.

Russells *et al.* (2012) executed a roof water harvesting and filtration project in Australia. They discussed about rain water quality, different filter treatments and potable rainwater use and they established storm water management technology and redefines it to help for growing water supply demand in the city of Warrnambool.

Silva *et al.* (2013) developed an up-flow filtration system with down-flow backwashing operation. The concept was tested by building a prototype, in which the treatment efficiency for particle removal as well as the backwash efficiency were assessed for three different filter media. Results showed that the system designed under the proposed concept operated effectively with the correct selection of the filter medium. Therefore, the proposed rainwater treatment concept offers an opportunity to enhance water security by treating and using rainwater in buildings in an efficient, simple, and energy-free way.

2.3.5 Storage system

The storage facility is the core of the RWH system. In addition to having the appropriate volume capacity in relation to the catchment area, rainfall conditions and needs, it must be cost effective and durable in its installation and maintenance. Selection of the type of storage facility ultimately depends on the purpose of use, affordability, availability of supplies and materials. The following are the key considerations in design and operation of the storage facility:

- Water tight construction with a secure cover to keep out insects and other vermin, dirt and sunshine (exposure to sunlight will cause algal growth in stored water).
- Screened inlet to prevent particles and mosquitoes from entering the tank.
- Screened overflow pipe to prevent mosquito entry and breeding.
- In the case of cisterns, inclusion of a manhole (to permit insertion of a ladder) to allow access for cleaning.
- An extraction system that does not contaminate the water during operation (related to tap and pump installation).
- Soak away to prevent spilt water forming standing puddles near the tank (to minimize mosquito breeding).
- In the case of cisterns, a maximum height of 2 m (may be provided) to prevent buildup of high water pressure, unless additional reinforcement is used in walls and foundations.

2.4 Roof harvested rainwater quality

Water quality refers to the physical, chemical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. The most widely used definition of water quality is “the physical, chemical, and biological characteristics of water, usually in respect to its suitability for a designated use." As we all know, water has many uses, such as for recreation, drinking, fisheries, agriculture and industry. Rainwater is relatively free from impurities except those picked up by the falling drops from the atmosphere, but the quality of rainwater may deteriorate during harvesting and storage. Windblown dirt, leaves, fecal droppings from birds and animals, insects and contaminated litter on the catchment areas can be sources of contamination of rainwater, leading to health risks. Poor hygiene in storing water in and abstracting water from tanks or at the point of use can also represent a health concern. However, risks from these hazards can be minimized by good design and practice. Well designed rainwater harvesting systems with clean catchments and storage tanks supported by good hygiene at point of use can offer drinking water with very low health risk and vice versa. Microbial contamination of collected rainwater indicated by E. *coli* (or, alternatively, thermo tolerant coliforms) is quite common, particularly in samples collected shortly after rainfall. Pathogens such as Cryptosporidium, Giardia, Campylobacter, Vibrio, Salmonella, Shigella and Pseudomonas have also been detected in rainwater (Crabtree *et al.*,1996). If water quality testing is possible, the main focus should be on microbiological testing using tests such as fecal coliforms, Enterococci, and the simple H_2S test. World Health Organization guidelines (WHO, 1996) states that fecal bacteria should not be detectable per 100 ml of rainwater sample. However, Fujioka, 1994 stated that more realistic standard may be 10 fecal coliforms/100 ml. There are several recent studies that have used thermo tolerant coliforms and E.*coli* as indicator organisms to predict the presence of pathogenic organisms. These have shown that either there was no correlation between thermo tolerant coliforms and the presence of pathogens or there were no pathogens present when thermo tolerant coliforms were detected. On the other hand, the absence of thermo tolerant coliforms does not indicate the absence of Cryptosporidium and Giardia spp.(Gadgil, 1998). If water treatment is undertaken, thermo tolerant coliforms could be destroyed but high resistant organisms like Cryptosporidium and Giardia spp. can survive (Despins*et al.*, 2009).

The permissible limit of various quality parameters based on different standards is given below (Table 2.1 and Table 2.2).

Table 2.1 Quality parameter with different standards

Quality parameter	**Standard**		
	WHO	**BIS 10500 2012**	**EPA**
pH	6.5-8	6.5-8.5	6.5-8.5
Turbidity (NTU)	5	1-5	--
Colour (Hazen unit)	15	15	15
Odour	Agreeable	Agreeable	3 threshold odor numbers
Total dissolved solids(mg/l)	1000	500	500
Total suspended solids(mg/l)	--	--	600
Conductivity (µmhos/cm)	600	--	--
Chloride (mg/l)	250	250	250
Copper(mg/l)	2	0.05	1
Zinc(mg/l)	3	5	5
Iron(mg/l)	0.3	0.3	0.5-50
Manganese(mg/l)	0.5	0.1	0.05
Lead (mg/l)	0.01	0.01	0
Total hardness (mg/l)	100	600	--
Total coliforms (no. /100ml)	0	0	0

Table 2.2 WHO's drinking water standards for organic compounds

Group	**Substance**		**Formula**	**Health based guideline by the WHO**
Chlorinated alkanes	Carbon tetrachloride		$C Cl_4$	2 µg/l
	Dichloromethane		$C H_2 Cl_2$	20 µg/l
	1,1-Dichloroethane		$C_2 H_4 Cl_2$	No guideline
	1,2-Dichloroethane		$Cl CH_2 CH_2 Cl$	30 µg/l
	1,1,1-Trichloroethane		$CH_3 C Cl_3$	2000 µg/l
Chlorinated ethenes	1,1-Dichloroethene		$C_2 H_2 Cl_2$	30 µg/l
	1,2-Dichloroethene		$C_2 H_2 Cl_2$	50 µg/l
	Trichloroethene		$C_2 H Cl_3$	70 µg/l
	Tetrachloroethene		$C_2 Cl_4$	40 µg/l
Aromatic hydrocarbons	Benzene		$C_6 H_6$	10 µg/l
	Toluene		$C_7 H_8$	700 µg/l
	Xylenes		$C_8 H_{10}$	500 µg/l
	Ethylbenzene		$C_8 H_{10}$	300 µg/l
	Styrene		$C_8 H_8$	20 µg/l
	Polynuclear Aromatic Hydrocarbons (PAHs)		$C_2 H_3 N_1 O_5 P_{1\ 3}$	0.7 µg/l
Chlorinated benzenes	Monochlorobenzene (MCB)		$C_6 H_5 Cl$	300 µg/l
	Dichlorobenzenes (DCBs)	1,2-Dichlorobenzene (1,2-DCB)	$C_6 H_4 Cl_2$	1000 µg/l
		1,3-Dichlorobenzene (1,3-DCB)	$C_6 H_4 Cl_2$	No guideline
		1,4-Dichlorobenzene (1,4-DCB)	$C_6 H_4 Cl_2$	300 µg/l
	Trichlorobenzenes (TCBs)		$C_6 H_3 Cl_3$	20 µg/l
Miscellaneous	Di(2-ethylhexyl)adipate (DEHA)		$C_{22} H_{42} O_4$	80 µg/l
	Di(2-ethylhexyl)phthalate (DEHP)		$C_{24} H_{38} O_4$	8 µg/l

Table 2.2 Continued

organic constituents	Acrylamide		$C_3 H_5 N O$	0.5 µg/l
	Epichlorohydrin (ECH)		$C_3 H_5 Cl O$	0.4 µg/l
	Hexachlorobutadiene (HCBD)		$C_4 Cl_6$	0.6 µg/l
	Ethylenediaminetetraacetic acid (EDTA)		$C_{10} H_{12} N_2 O_8$	200 µg/l
	Nitrilotriacetic acid (NTA)		$N(CH_2COOH)_3$	200 µg/l
	Organotins	Dialkyltins	$R_2 Sn X_2$	No guideline
		Tributil oxide (TBTO)	$C_{24} H_{54} O Sn_2$	2 µg/l

2.5 Effect of roofing material on the quality of rainwater

Roofs are the most desirable surfaces for rainwater harvesting in urban areas. Studies have reported that harvested rainwater quality was significantly affected by the types of roofing materials. Like other untreated water collection methods, the use of roof water harvesting systems may lead to serious human health problems if natural and anthropogenic pollution sources such as feces of birds, small mammals and reptiles, decay of accumulated organic debris, atmospheric deposition of inorganic and organic chemical compounds, etc., contaminate rain or harvested water during its collection and storage. The toxicity of harvested rainwater could derive from different parts of the system, i.e. roof catchment surface, pipes and cistern (Gumbs and Dierberg, 1985).The deposition of various pollutants from the atmosphere into roof surfaces during the dry period greatly influences the runoff water quality from roof catchment systems. The longer the dry period between rainfall events, the greater is the amount of pollutants deposited on the roof surfaces.

Susumu *et al.* (2001) studied the physicochemical speciation of molybdenum in rain water. For this study, a combination of a sensitive catalytic determination method with filtration and ultrafiltration has been used for the physicochemical speciation of molybdenum in natural and synthetic rain water samples. They revealed that the traces of molybdenum in the successive rainfall sample were found in a fraction with smaller molecular weights $<10^3$ Da and characterized as labile forms, i.e. simple molybdate ions.

Various studies have been conducted to thoroughly examine the effect of roofing material on the quality of harvested rainwater from the standpoint of suitability for domestic use. The type and condition of the roofing material is known to affect the water quality (Peter, 2002). Paint coatings on the roofing tiles will oxidise through weathering. When degrades, these coatings can be washed into the rainwater storage tank. Tiles with colour impregnated into them will not encounter this problem (Urban Rainwater Systems Pty Ltd, 2004). Roofs painted with lead based paints and lead and copper piping for conveying water to or from the storage tank may however result in unacceptable concentration of heavy metals in rainwater supply. If asbestos or fibro-cement roofing is used, it should be left undisturbed. Working with asbestos is hazardous to health because of inhalation of fibers. In most countries, the use of asbestos as a roofing material is discouraged.

Bineesh *et al*. (2004) conducted a research study on salient features of ground water resource and quality of drinking water at KCAET Campus, Tavanur, Malappuram, Kerala. They found that drinking water contains high coliform content and low pH. Rest of the water quality parameters remained in the tolerable limits.

Compared to road runoff, roof runoff is relatively clean, because the roof areas are rarely affected by human activities. The main factors affecting roof runoff quality include type, age, and roughness of the roof. The compounds contained in roofing materials can leach into the runoff (Chang *et al.,* 2004) and older roofs contain large amounts of suspended solids. Rainfall characteristics (e.g., precipitation, rainfall intensity, ADWP) and environment characteristics (e.g., seasonal variation, atmospheric pollution, roof surrounding environment) influence the quality of roof water. In general, roof temperatures are much higher than temperatures of other surfaces due to lower albedo and reduced shading effects from surrounding trees, which increases the rates of chemical reactions and organic decomposition of materials that have accumulated on rooftops. In addition, the leaves, dead insects, and bird waste, added to roofs by interception and deposition affect the water quality of the roof runoff.

The urban water quality using artificial rainfall at South-East Queensland, Australia was investigated by Herngren *et al*. (2004). They described how artificial rainfall, using a specially designed highly portable rainfall simulator was employed in order to generate water quality data from urban environments. The study reported that the rainfall simulator is a reliable tool for urban water quality research and can be used to simulate pollutant wash-off.

Mohammed *et al*. (2005) studied the catchment effects on rainwater quality and microbial count enhancement by storage. In this study quality of stored rainwater was examined in storage tanks of two buildings in Seoul National University, Seoul. It can be concluded from the results that the water is apparently dirty in small tank, shows high contamination by dust, sand, leaves and other chemicals and materials (grease, oil etc.). High pH and turbidity values in main tank is introduced by small tank due to terrace catchment when compared with weir sample which is only roof collected water. The quality is improved after first flush of rainfall. The first flush of rainfall must be diverted for improved microbial quality of stored rainwater or should be treated in an appropriate way.

Evans *et al*. (2006) reported the effect of weather on the microbial composition of roof harvested rainwater. This study involved analysis of direct roof runoff at an urban housing development in Newcastle, on the east coast of Australia. A total of 77 samples were collected during 11 separate rainfall events, and microbial counts and mean concentrations of several ionic contaminants were matched to climatic data corresponding to each of the monitored events. Results indicated that airborne microorganisms represented a significant contribution to the bacterial load of roof water at this site, and that the overall contaminant load was influenced by wind velocities, while the composition of the load varied with wind direction.

Sandeep and Magar (2006) conducted a feasibility study of Rainwater Harvesting for the buildings in the premises of Fr.Agnel Technical Education Complex, Vashi. The research has been carried out with objectives of, 'Save Electricity & Water. In a city like Mumbai, where the ground surface is heavily mineralised, the main way to harvest rainwater is to tap the water falling on the terraces of buildings. Thus, in residential or commercial buildings, the drain pipes of terraces should be connected to the drains but to a recharge well or recharge pit. The same bore well or tube well then can be used for pumping out the groundwater.

While metal roofs are commonly recommended for rainwater harvesting applications, the metal roofs did not produce clearly superior harvested rainwater quality as compared to the other roofing materials. Concrete tile and cool roofs also appear to be good options for rainwater harvesting catchments, given the overall similarity in harvested rainwater quality. The rainwater harvested from the metal roof showed lower concentrations of fecal indicator bacteria. This might be due to the low emissivity of metal, resulting in higher surface temperatures on the roof .From various studies highest number of bacterial pathogens was found in the wooden shingle roof samples, most likely because of the greater presence and growth of lichens, mosses and plants on this roofing material (Mendez *et al.*, 2011).

Mooyoung *et al.* (2012) conducted a study on the quality of roof harvested rainwater – a comparison of different roofing materials. The objective of the study reported in this paper was to assess the quality of harvested rainwater on the basis of the roofing materials used and the presence of lichens/mosses on the roofing surface. Four pilot structures with different roofing materials (i.e., wooden shingle tiles, concrete tiles, clay tiles and galvanized steel) were installed in afield. The galvanized steel was found to be the most suitable for rainwater harvesting applications, with their resulting physical and chemical water quality parameters meeting the Korean guidelines for drinking water quality. In the galvanized steel case, the relatively high water quality was probably due to ultraviolet light and the high temperature effectively disinfecting the harvested rainwater. It was also found that the presence of lichens and mosses may adversely affect the physical, chemical and microbiological quality of rainwater.

Sergio *et al.* (2013) conducted a study on the influence of volcanic activity on the quality of water collected in roof water catchment systems at Stromboli Island, Italy. In this study the concentrations of major and trace elements in rainwater, collected for domestic use in roof catchment systems, have been determined in order to evaluate the interaction of water with gases and suspended particles of volcanic origin in an area extremely influenced by persistent volcanic activity. Additional attention has been focused on the constructive style and use of the RWCS and their role in modifying the quality of collected water, to evidence potential human health issues arising from the continuous use of this resource as drinking water.

Ruida *et al*. (2014) conducted a study on quality and seasonal variation of rainwater harvested from concrete, asphalt, ceramic tile and green roofs in Chongqing, China. In this study, they examined the effect on the quality of harvested rainwater of conventional roofing materials (concrete, asphalt and ceramic tile roofs) compared with alternative roofing materials (green roof). The results showed that the ceramic tile roof was the most suitable for rainwater-harvesting applications because of the lower concentrations of leachable pollutants. However, this study reports that the green roof was not suitable for rainwater harvesting applications. In addition, seasonal trends in water quality parameters showed that pollutants in roof runoff in summer and autumn were lower than those in winter and spring. This study revealed that the quality of harvested rainwater was significantly affected by the roofing material. Therefore, local government and urban planners should develop stricter testing programs and produce more weathering resistant roofing materials to allow the harvesting of rainwater for domestic and public uses.

2.6 Purification methods of roof harvested rainwater

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water. The goal of this process is to produce water fit for a specific purpose. Most water is disinfected for human consumption (drinking water) but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications. In general the methods used include physical processes such as filtration, sedimentation, and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light. The purification process of water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi and a range of dissolved and particulate material derived from the surfaces with which rain has interacted (Yaziz*et al.*,1989)

2.6.1 Chlorination

Water chlorination is the process of adding chlorine to water. Chlorine can be applied for the deactivation of most microorganisms and it is relatively cheap. Chlorination has to be applied after removal of the harvested rainwater from the storage tank, because chlorine may react with organic matter which settled to the bottom of the tanks and form undesired by products (Ying and Sunny, 2013). Chlorination should meet the amount of 0.4 to 0.5 mg/*l* free chlorine and can be done by chlorine tablets or chlorine gas. One limit of disinfection by chlorination is that some parasitic species have shown resistance to low doses of chlorine. Chlorination to kill bacteria is widely recommended as sterilization for rainwater collection systems but generally chlorinated water is not well liked by users and the chemicals used can be dangerous if misused.

2.6.2 Ultraviolet Light

An alternative for disinfecting water is Ultraviolet (UV) light. UV lights have been used for nearly a century in Europe and are now common in the US.

With UV lights, the water must always pass through a filtration system first. If no filter is used, pathogens and bacteria will cast shadows in the flowing water, thereby allowing live organisms to pass through unharmed. UV light works by penetrating an organism’s cell walls and disrupting the cell’s genetic makeup, making it impossible to reproduce and rendering it harmless. UV lights do not change the chemical composition of the water and leave behind no by-products. For UV to be effective the right light dose must be used to a specific unit of water and the water must be clear of suspended solids and other particulates. UVA radiation inactivates microorganisms by damaging proteins and producing hydroxyl and oxygen radicals that can destroy cell membranes and other cellular components (Sinha and Hader, 2002). Hamamoto, *et al*. (2007) demonstrated the ability of UVA-LEDs at 365 nanometre to inactivate bacteria in water. They found that E. *coli* were reduced by greater than 5 log at a dose of 315 J/cm^2.

2.6.3 Membrane filtration

Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 µm including giardia and cryptosporidium. Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions. Membrane filtration involves pushing water through a layer of material. Pressure-driven membrane technologies include microfiltration, ultrafiltration, nano filtration and reverse osmosis (Ward *et al*., 2014). It is one of the few technologies capable of removing pharmaceuticals, and creates no byproducts. Membrane technologies are more costly than other alternatives, but prices are rapidly declining. Most water purification experts expect membrane technology to become the prevalent technology in smaller systems over time as their price drops.

2.6.4 Distillation

The last commonly available purification technology is distillation. Distillation separates the water from the impurities through heating and then collecting the condensation. It is very energy intensive and loses about 5-10percentage of the water due to evaporation. Distillation removes almost all substances from the water with the exception of volatile organic chemicals that evaporate easily. To this end, some distillation systems are also equipped with carbon filters to remove the volatile organic carbons. Distillation works slowly to reduce energy requirements and will store the purified water in a tank for later use. In addition to using a lot of electricity to operate, distillation systems generate heat. It will remove heavy metals, salts, and other chemical pollutants that can harm your health. Basically, the process involves boiling water so that it leaves behind all the stuff that has contaminated it, and then collecting the vapor and allowing it to condense back into liquid water (Kahinda*et al.*,2007). You can create a simple distilling apparatus simply by suspending a cup by attaching it to the inside of a large pot's lid, and then putting a layer of water in the bottom of pot and boiling it for 20 minutes. As the pot cools afterward, the water that drips down into the cup is purified. If concerned about using up fuel, it's also possible to build a solar energy-powered distiller.

2.6.5 Filters

The filter is used to remove suspended pollutants from rainwater collected over roof. The filter unit is a chamber filled with filtering media such as fiber, coarse sand and gravel layers to remove debris and dirt from water before it enter the storage tank or recharge structures. Filters are used for treatment of water to effectively remove turbidity, colour and microorganisms. After first flushing of rainfall, water should pass through filters. Commonly using filters are charcoal, sand and micromesh filters. Charcoal filter can be made in a drum or an earthen pot. The filter is made of gravel, sand and charcoal, all of which are easily available. And sand filters have commonly available sand as filter media. Sand filters are easy and inexpensive to construct. These filters can be employed for treatment of water to effectively remove turbidity (suspended particles like silt and clay), colour and microorganisms (Rangwala, 2003). In a simple sand filter that can be constructed domestically, the top layer comprises coarse sand followed by a 5-10 mm layer of gravel followed by another 5-25 cm layer of gravel and boulders.

The micro-mesh screen can filter debris in the 80-100 micron size which is beneficial for potable or indoor fixture systems which require superior filtration. Filters are measured in microns. For comparison, sand is about 100 – 1,000 microns, a human hair is about 100 microns, a particle of dust is about 1 micron and a virus can be smaller than 0.01 micron. The screening stage stops debris and large particles from entering the rainwater storage tank (Thomas *et al.,* 2004). Rainwater collected from the roof and stored in tanks barely meets quality levels so that it can be directly used for showers, washing machines, gardening and other domestic uses.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The details of the description of study area, design, construction and evaluation of various filters and first flush for roof water harvesting systems are presented in this chapter.

3.1 Study Area

Developments of filters, first flush system and their evaluation have been conducted in the campus of Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur, Malappuram, Kerala, India. Geographical reference of the study area is 10º 51' 20" N latitude and 75º 59' 5" E longitude. Average annual rainfall of the area for the last 30 years is 294 cm. About 75percentage of the annual rainfall is received through South West monsoon (June to September) and the balance 25 percentage is through North East Monsoon (October to November) and summer rains (December to May). The summer rain is very meagre with a usual variation of 0 to 5 percentage. Climate is humid tropic with a mean annual maximum temperature of 30ºC, minimum temperature of 23.5ºC and relative humidity 75 percentage. Mean monthly rainfall and temperature of the study area is shown in Fig 3.1.

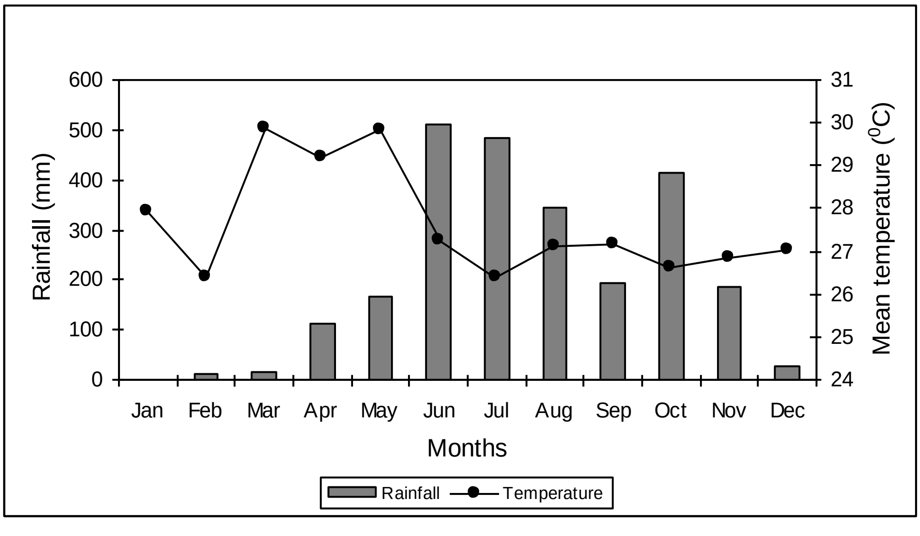

Fig 3.1 Mean monthly rainfall and temperature of the study area

3.2 Collection of direct rainfall

Direct rainfall samples of the study region have been collected during the period from June 2014 to October 2014. Samples were collected by placing a 20 *l* plastic bucket on a clean open area like courtyards, open terraces etc. These samples were collected to have sufficient understanding on the direct rainfall quality. It will also be of great use to evaluate the roll of roofs in incorporating impurities to roof water harvesting system.

3.3 Different roofs considered for the study

As rooftop impurities vary with roofing materials, different roofs have been considered in this study. Roof water from different roofs has been collected to carry out the performance evaluation of different mesh filters and the first flush system. Roof top impurities were also collected from different roofs in order to prepare synthetic roof water to facilitate the testing of different micro mesh filters in the absence of actual rains. The roof catchment selected were asbestos roof, clay tiled roofs and concrete roof. During rainfall events, rooftop water was collected from various roofs during the period from July to September 2014 and stored in a tank of 100 litre capacity.

3.4 Description and development of micro mesh filters

3.4.1 Description of existing micro mesh filters

A 100 micron upward flow mesh filter developed by the department of land and water resources and conservation engineering has been used for performance evaluation in this study. Filter was tested for performance evaluation under actual rainfall and with synthetic roof top water. Sectional view of the upward flow filter setup is shown in Fig 3.2. The set up consist of a filter element made of 100 micron stainless steel mesh wound on a slotted 50mm PVC pipe. The filter element is placed in a 90mm PVC casing pipe. It is hung concentrically inside the casing pipe by fitting to the end cap of the casing pipe. The end cap of the casing pipe is threaded. Hence the filter element can be taken out of the casing pipe for washing by loosening the threaded end cap. A back wash cleaning provision for the filter unit was also provided at the bottom. Height of the filter element was 30 cm and the 100 micron mesh surface area was 470 cm^2. The total height of filter unit with casing was 75 cm.

Design and arrangement of the existing micro mesh filter unit is shown in the Fig 3.2.

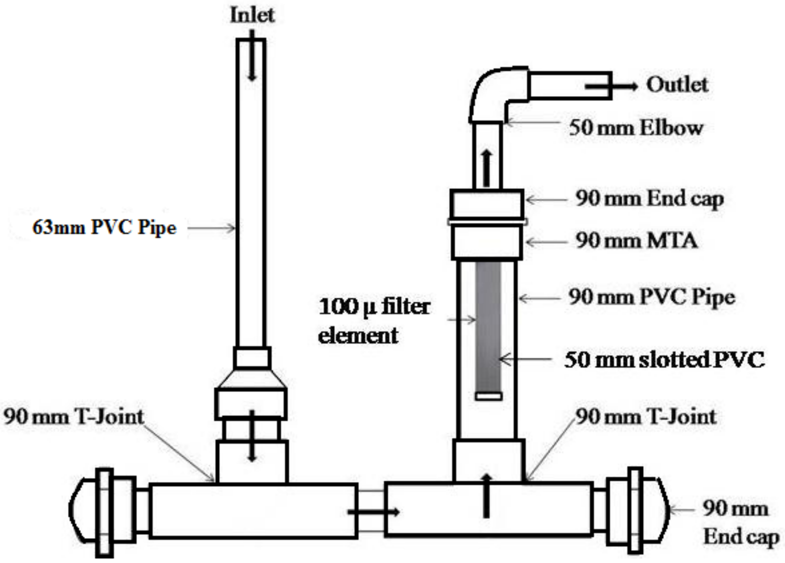

Fig. 3.2 Existing upward flow micro mesh filter

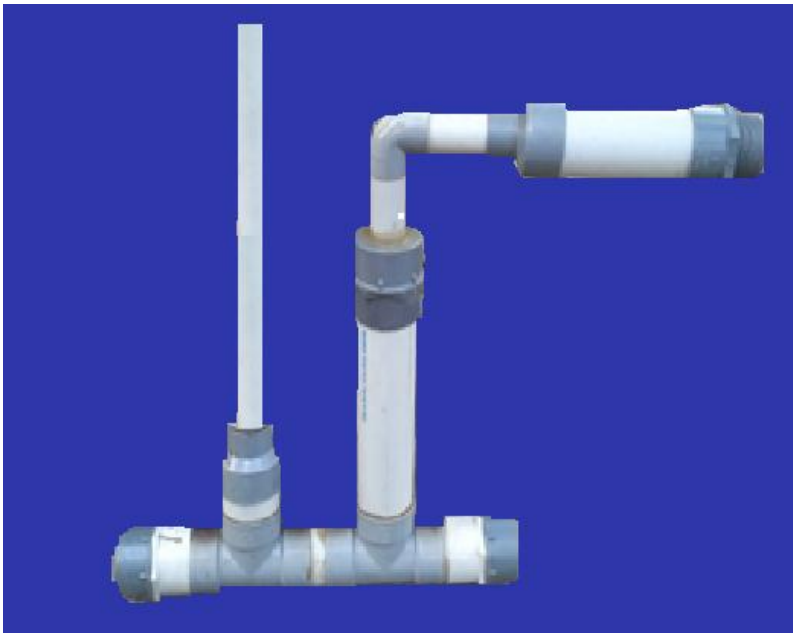

Plate 3.1 Experimental setup of roof water purification

3.4.2 Development of modified mesh filters

This study includes the development of 60, 40 and 25 micron mesh filters. In all cases the micro meshes used were made of stainless steel. To make the filter element, 50 mm PVC pipe of 35 cm length taken and slots of 5 mmϕ were made on it at an approximate spacing of 15mm center to center in the case of 60 and 40 micron mesh sizes. In the case of 25 micron mesh size, slots were given at more close intervals to compensate for the reduction in the filtration rate due to lower mesh size. Mesh area and slot area of different filter elements are shown in the Table 3.1.

Table 3.1 Mesh area and slot area of different filter elements

Mesh size (μ)	**Mesh area (cm^2)**	**No. of slots**	**Slot area (cm^2)**
60	447.45	229	44.94
40	447.45	124	24.33
25	447.45	296	58.09

The sectional view of the filter elements are shown in Fig 3.3. The filter elements were fitted in a casing pipe of 90 mmϕ PVC. With the help of threaded end cap, the unit is made easily attached and detached to the filter assembly as of the existing filter unit. A back wash cleaning provision for the filter unit is also provided at the bottom using 90mm threaded end cap. Height of the element was 35cm and the micron mesh area was 0.047 m^2. The total height of filter unit was 75 cm.

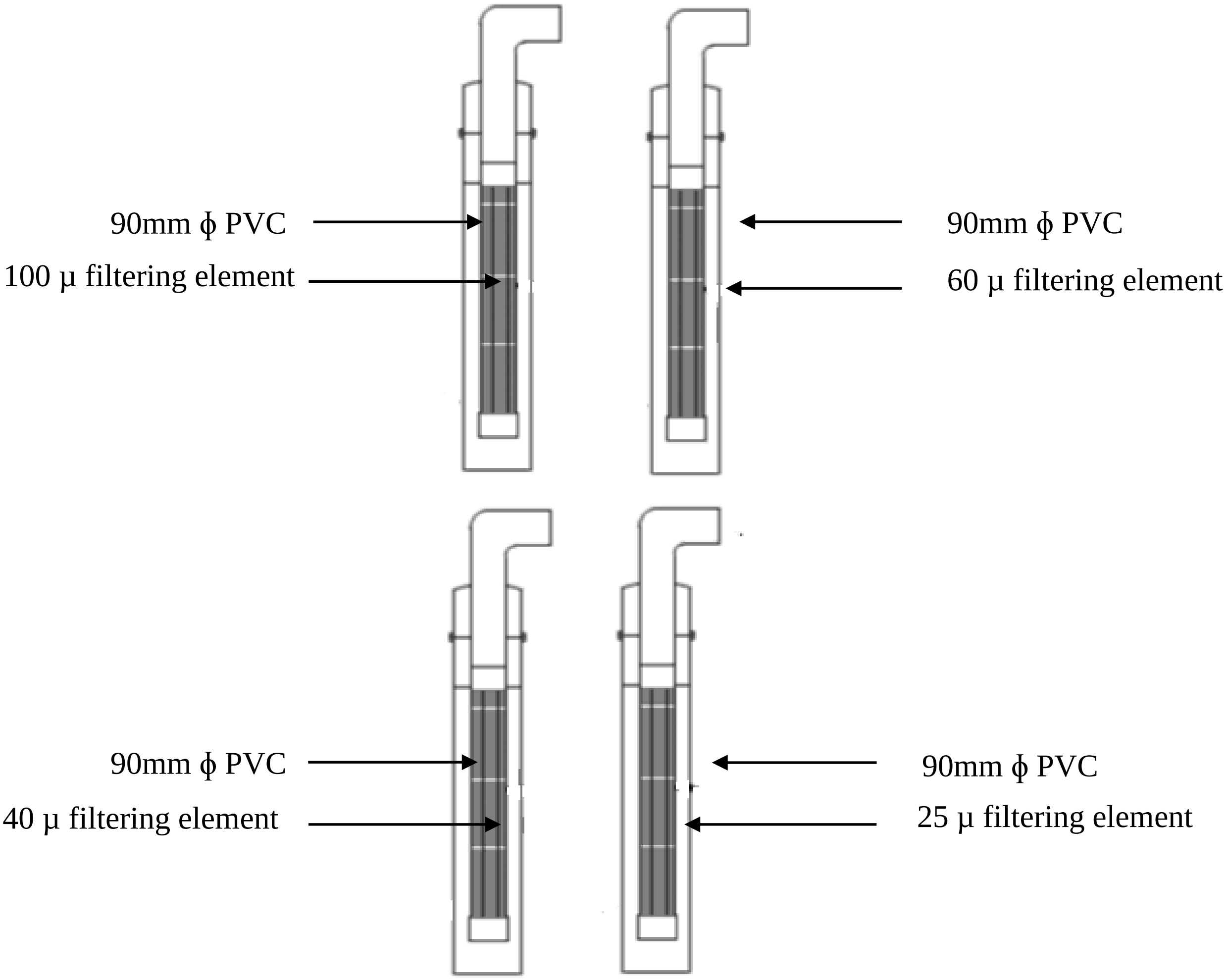

Fig. 3.3 100μ, 60μ, 40μ and 25μ filter unit

3.5 Design and development of first flush system

First flush or foul flush unit aims to divert the impure initial rooftop rainwater collected. The dirtier water initially collected by a rainwater harvesting system is known as the ‘first flush’ or ‘foul flush’, and is the main source of contamination in any rooftop rainwater harvesting system. Removal of this water is important as the initial collect the impurities present in the atmosphere and all kinds of contaminants present in the roof and gutter system. Impurities floating in the air could be dust particle. Contaminants in the roof will be dust, dead leaves, animal excreta, dead insect and other particulate matter. Studies have shown a tremendous drop in fecal bacteria levels when the roof is flushed before water enters the storage tank. Bacteria also like to live in decaying leaves and other organic matter that collects at the bottom of the first flush tank. A first flush diverter facilitates a reasonable level of cleaning of the roof and gutters, so there is less rubbish on the tank’s bottom.

The sectional view of first flush system is shown in the Fig 3.5. The main component of the first flush is a floating ball valve maintained in a chamber made of PVC pipe. The system was constructed using 160 mm diameter PVC pipe which acts as the storage chamber for the first runoff from the roof to be stored temporarily. First flush is connected to the conveyance pipes before the filter unit, using PVC connectors and reducers. The total capacity of the system is worked out based on the roof runoff corresponding to 1mm initial rainfall. The capacity of the first flush chamber is made as 20 litre, so as to make it suitable for a 20m^2 roof catchment, which will be more than sufficient for any domestic roof water harvesting systems in Kerala. Bottom end of the first flush chamber is closed by a PVC end cap. When the first rainwater is filled up to the maximum capacity of the system, the ball will close and will isolate the chamber from the conveyance pipe and prevent the mixing of first rainwater with the subsequent coming down roof water. A small dripper hole is provided at the bottom of the first flush chamber so that chamber becomes empty before the next arrival of rainfall. The first flush system help to reduce the impurity load going to the mesh filter and reduces the frequency of its cleaning requirement in addition to the overall water quality improvement.

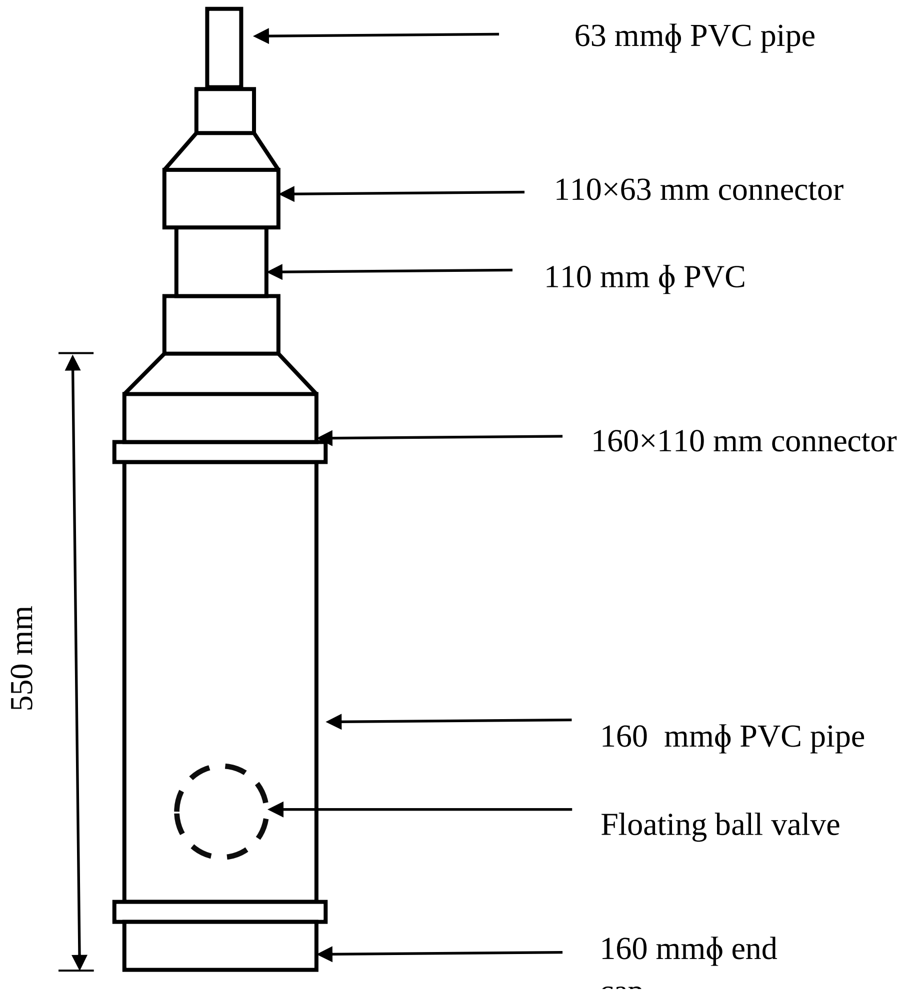

Fig 3.5 First flush system

3.6 Performance evaluation of the mesh filter

The existing 100 micron mesh filter and the newly developed filters of mesh size 60, 40 and 25 microns were thoroughly tested under different conditions. Conducting the experiment under actual rainfall condition was practically not possible due to the unpredictable nature of rainfall and their arrival during odd time of a day. To solve these issue synthetic roof water was prepared to carry out the test. Synthetic roof water having characteristics very close to the natural roof water was prepared. This synthetic roof water was allowed to pass through different sized mesh filters. Roof water samples were collected from the inlet and outlet end of the filter unit for quality analysis.

3.6 Preparation of synthetic roof water

Roof water impurity level varies depending on number of factors. The most important among them are the type of roofing material, shape of roof, intensity variation in rainfall and the length of antecedent dry period between two rainfall events. Natural roof water quality of different roofing materials viz. asbestos, concrete and tile of the study region are have been reported by Shijila and Sathian, 2014. It was found that impurity level varies between 400 mg/*l* to 1000 mg/*l*. This information has been used for the preparation of synthetic roof water.

Natural roof water from three different roofs viz. asbestos, concrete and tile were collected and stored in containers. Roof top impurities from different roofs were collected separately and it was mixed with the stored water for conducting the experiment. Roof water samples were prepared in two different concentrations of suspended matters viz. 600 mg/*l* and 800 mg/*l*.

3.7 Performance evaluation of the first flush system

Basically the first flush system for roof water harvesting is provided to collect and divert the highly impure water generated from roof during the initial few minutes of starting of rainfall events. It is designed to check the mixing of first coming highly impure roof water with the next coming cleaner roof water. Evaluation of the system was carried out different in two modes: by not connecting with the filter and by connecting with the filter. Conducting the experiment under actual rainfall condition was very difficult as has been explained in the evaluation of mesh filters, synthetic roof waters were used in this case also.

Performance of the first flush unit was performed by connecting the unit before the mesh filter of the roof water harvesting arrangement. After the first flush all the four different mesh filters were connected in series, one at a time with the first flush system. Samples for water quality testing were collected from the inlet and from the outlet end of the mesh filter. The experiment was repeated for each mesh filter cum first flush combination. All the water quality parameters tested in the case of filter alone case has also been done for filter cum first flush combination.

3.8 Working of first flush and filter under actual rainfall

Rainwater coming down from the rooftop through the gutter and downpipe is conveyed to the first flushing unit having 20 *l* capacity. This first flush tank collect 20 *l* of initially generated most impure water. Capacity of the first flush tank is made as 20 *l* to accommodate 1 mm of initial rainfall over a roof area of 20 m^2.As the water level rises in the first flush diverter chamber the ball floats on the water surface and once the chamber is full, the ball presses against the inlet to the flush chamber and closes it, and thereby preventing any further entry of roof water into it. The subsequent flow of water is then automatically directed to the up flow filter system along a 90 mm pipe where the incoming flow velocity is reduced and the debris is allowed to settle. Then, the rainwater with reduced velocity of flow move upward through the annular space between the casing pipe and the filter element. Water then passes through the micro mesh of the filter where removal of suspended particles takes place. The filtered water then moves to the storage tank. The entire movement of water from the roof to the storage tank takes place under gravity force without expending any additional energy.

Impure water collected in the foul flush chamber will be drained slowly by dripping water through the dripper hole of 2 *l*/h discharge capacity. It may take about 10 hours for emptying the chamber. Thus the first flush chamber will be ready to receive the next lot of initial incoming roof water. The chamber can be cleaned by opening the end cap at the bottom. As the micro mesh filter unit is designed for the pass of water in upward direction, major portion of the suspended particles is settled at the bottom of its annular space and will reduce the load of impurities reaching the mesh filter. Impurities settled at the bottom can be removed by opening the end cap provided at the bottom and flushing.

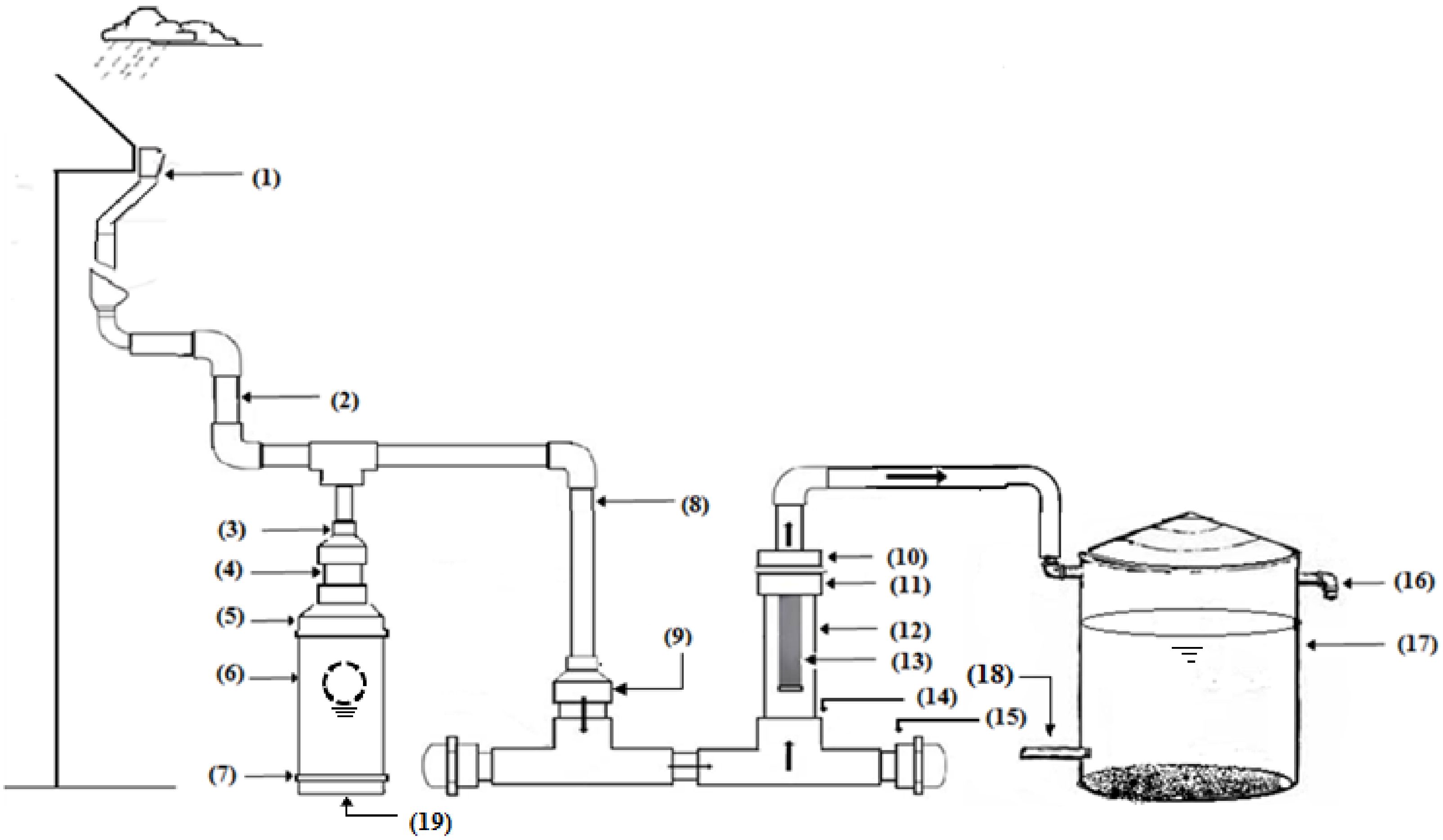

Fig 3.6 Upward flow filter with first flush system

(1) Gutter
(2) 63mmϕ PVC pipe
(3)110x63mm Connector
(4)110mmϕ PVC pipe
(5)160x110mm Connector
(6) 160mm PVC
(7) 160mm End cap
(8) 63mmϕ PVC
(9) 90x63mm Connector
(10)90mm End cap
(11) 90mm MTA
(12) 90mmϕ PVC pipe
(13) Filter element
(14)90mm T joint
(15) 90mm End cap
(16) Overflow pipe
(17) storage tank
(18) Outflow pipe
(19) Dripping hole

3.9 Estimation of water quality parameters

Various physical, chemical and biological qualities of the inflow and outflow samples of the filter and that of the first flush system and also the quality of direct rainfall were analyzed at different laboratories of Kerala Agricultural University. Mainly the analysis was carried out at soil and water laboratory of KCAET Tavanur and Radio Tracer Lab of Horticultural College, Vellanikkara, Thrissur. All the tests were carried out as per BIS standards. Details of different tests carried out are presented below.

3.9.1 Physical analysis using water quality analyzer

A water quality analyzer of “SYSTRONICS 371” was used to carry out the physical analysis of the roof top rain water. It is a micro controller based instrument for measuring pH, dissolved oxygen, salinity, conductivity, TDS, temperature, colorimetric and turbidity in water sample one at a time. The analyzer provides both automatic and manual temperature compensation. Calibration or standardization of the instrument was done with standard solutions. Provision for storing calibration of all appropriate modes is provided with the help of battery backup. This data can be further used for measuring the unknown, without recalibrating the instrument even after switching it off. A 20 x 2 alphanumeric LCD display along with 14 keys enables the user to select, set and operate the unit with ease. All the results are available on the display.

The important physical parameters which include pH, electrical conductivity and TDS of the rainwater and roof water samples collected for the study were tested with water quality analyser. Procedure adapted for testing of roof water samples collected is presented below.

Plate 3.2 Systronics water quality analyzer

3.9.1.1 pH

The acidity or alkalinity of water is expressed as pH. The pH of an aqueous solution is a measure of the acid base equilibrium achieved by various dissolved compounds. The Bureau of Indian Standards (BIS) recommendation of pH for drinking water is 6.5 to 8.5. Water quality analyser determines the pH using pH electrode. It consists of a glass bulb membrane, which gives it its name and an electrically insulating tubular body, which separates an internal solution and a silver or silver chloride electrode from the solution under study. The Ag or AgCl electrode is connected to a lead cable terminated with some connector that can hook up to a special voltmeter of the pH meter. The pH meter measures the potential difference and its changes across the glass membrane. The potential difference must be obtained between two points; one is the electrode contacting with the internal solution and the second point is obtained by connecting to a reference electrode, immersed in the studied solution.

Plate 3.3 pH electrode

3.9.1.2 Electrical conductivity

Conductivity is the capacity of water to conduct electric current which varies both with the number and types of ions the solution contains. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Pure water is not a good conductor of electricity.

The electrical conductivity of the water also depends on the water temperature. While the electrical conductivity is a good indicator of the total salinity, it still does not provide any information about the ion composition in the water. Many EC meters nowadays automatically standardize the readings to 25^{o}C. The commonly used units for measuring electrical conductivity of water are μS/cm (microSiemens/cm) or dS/m (deciSiemens/m). In the case of conductivity of the drinking water, the acceptable limit is up to 1500 µS/cm, according to BIS standards.

Plate 3.4 Conductivity cell

3.9.1.3 TDS

The total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. Therefore, the total dissolved solids test provides a qualitative measure of the amount of dissolved ions but does not tell us the nature or ion relationships. The total dissolved solids concentration can be related to the conductivity of the water, though the relationship is not constant. The relationship between total dissolved solids and conductivity is a function of the type and nature of the dissolved cations and anions in water. TDS is not a direct measure of a specific element or contaminant. An elevated TDS may be associated with an elevated water hardness, chemical deposits, corrosion by-products, staining, or salty bitter tastes. If the TDS content of the water is high, the primary recommendation would be to test the water for additional parameters, such as total hardness, iron, manganese, sodium, chloride, sulfate, alkalinity and nitrate, to determine the nature of the water quality problem. The TDS test is an ideal indicator of the potential for water quality problems. The presence of high levels of TDS would be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. No health based guideline value for TDS has been proposed. According to WHO water quality guidelines acceptable threshold of TDS is from 1000 to 1200 mg/*l*. Secondary Maximum Contaminant Level (SMCL) for total dissolved solids (TDS) is 500 mg/*l*. For fresh water, the relation between TDS and EC (electrical conductivity) is that the former is about half of the later. For harvested rainwater, TDS is affected by the catchment area and storage facility type and conditions. All the three parameters viz. pH, electrical conductivity, and TDS indirectly refer to the salt content of the water.

3.9.2 Total suspended solids by gravimetric method

Total suspended solids (TSS) are defined as the portion of total solids in a water sample retained by a glass fiber filter of pore size greater than 2 µ. Total suspended solids (TSS) are particles that are larger than 2 microns, found in the water column and anything smaller than 2 microns (average filter size) is considered as dissolved solid. Most suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solids concentration. These solids include anything drifting or floating in the water, from sediment, silt, and sand to plankton and algae. Organic particles from decomposing materials can also contribute to the TSS concentration. As algae, plants and animals decay, the decomposition process allows small organic particles to break away and enter the water column as suspended solids. Even chemical precipitates are considered a form of suspended solids. Total suspended solids are a significant factor in observing water clarity. The most important impurities in the roof water are suspended matters and it includes mainly organic moss and inorganic sand and fine dust particles. Hence, suspended particles are also been quantified through gravimetric measurements. For measuring suspended solids, the water is filtered through a fine filter (Whattmann**,** Grade 1, 110 mm ϕ) and the dry material retained on the filter is weighed. The drying was carried out for one hour in an oven at 105^o C.

$$\text{Total suspended solids in g/l} = \frac{w_2 - w_1}{v} \times 1000 \quad \text{….. 3.1}$$

Where,

W_1 = Initial weight of filter paper, g
W_2 = Weight of filter paper and the dry material retained on the filter, g
V = Volume of sample, ml

Plate 3.5 Gravimetric experimental setup

3.9.3 Metal concentration

Roof runoff shows high concentrations of heavy metals such as Zn, Fe, Cd, Cu and Pb (Forester, 1999; Gromaire *et al*., 2001). However, the pollutant loads are affected by roof materials, age, orientation, slope of the roofs, atmospheric depositions, rain events (intensity, antecedent dry period) and also meteorological conditions (Forester, 1999; *Chang et al*., 2004).The metal concentration in roof water has great bearing on its potability.

Test for metal concentration in the roof top rain water and direct rain water were undertaken at the Radio Tracer Laboratory of Kerala Agricultural University, Thrissur. A total of 8 metals were analyzed in the harvested rainwater, including copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K).

3.9.4 Microbiological parameters

To determine the suitability of harvested rainwater as a source of drinking water, the samples were tested for total bacteria, fungi, actinomycetes and E.*coli* content. Two tests were conducted to determine microbial load on the rooftop water such as enumeration of microorganisms from water by serial dilution method and MPN test for analysis of coliforms. The tests were undertaken at the microbiology lab at the Horticultural College of Kerala Agricultural University, Thrissur. Tests were successfully completed with the support of lab technical personnel. Procedures adopted in the case of different microbial analysis are presented below.

3.9.4.1 Serial dilution method

For unicellular microorganisms, such as bacteria, the reproduction of the cell reproduces the entire organism. Therefore, microbial growth is essentially synonymous with microbial reproduction. To determine rates of microbial growth and death, it is necessary to enumerate microorganisms, that is, to determine their numbers. The specific procedure of the test is given below.

1. Liquefy six agar deep tubes in an autoclave or by means of boiling. Cool the molten agar tubes and maintain in a water bath at 45 degrees centigrade.
2. Label the E. *coli* culture tube as Number 1 and the seven 9-ml water blanks as Number 2 through 8. Place the labeled tubes in a test tube rack. Label the petri dishes 1A, 1B, 2A, 2B, 3A, and 3B.
3. Mix the E. *coli* culture (tube Number 1) by rolling the tube between the palms of hands to ensure even dispersal of cells in the culture.
4. With a sterile pipette, aseptically transfer 1 ml from the bacterial suspension tub Number 1 to water blank tube Number 2. Discard the

pipette in the beaker of disinfectant. The culture has been diluted 10 times to 10^{-1}.

5. Mix tube Number 2 and with a fresh pipette transfer 1 ml to tube Number 3. Discard the pipette. The culture has been diluted 100 times to 10^{-2}.
6. Mix tube Number 3 and with a fresh pipette transfer 1 ml to tube Number 4. Discard the pipette. The culture has been diluted 1000 times to 10^{-3}.
7. Mix tube Number 4 and with a fresh pipette transfer 1 ml to tube Number 5. Discard the pipette. The culture has been diluted 10,000 times to 10^{-4}.
8. Mix tube Number 5 and with a fresh pipette transfer 0.1 ml of suspension to Plate 1A. Return the pipette to tube Number 5 and transfer 1 ml to tube Number 6. Discard the pipette. The culture has been diluted 100,000 times to 10^{-5}.
9. Mix tube Number 6 and with a fresh pipette transfer 1 ml of suspension to Plate 1B. Return the pipette to tube Number 6 and transfer 0.1 ml to tube Number 6 and transfer 1 ml to tube Number 7. Discard the pipette. The culture has been diluted 1,000,000 times to 10^{-6}.
10. Mix tube Number 7 and with a fresh pipette transfer 1 ml of suspension to Plate 2B. Return the pipette to tube Number 7 and transfer 0.1 ml to Plate 3A. Return the pipette to tube Number 7 and transfer 1 ml to tube Number 8. Discard the pipette. The culture has been diluted 10,000,000 times to 10^{-7}.
11. Mix tube Number 8 and with a fresh pipette transfer 1 ml of suspension to Plate 3B. Discard the pipette. The dilution procedure is now complete.
12. Check the temperature of the molten agar medium to be sure the temperature is 45 degrees centigrade. Remove a tube from the water bath and wipe the outside surface dry with a paper towel. Using sterile technique, pour the agar into Plate 1A and rotate the plates gently to ensure uniform distribution of the cells in the medium.
13. Repeat step 12 for the addition of molten nutrient agar to Plates 1B, 2A, 3A, and 3B.

14. Once the agar has solidified, incubate the plates in an inverted position for 24 hours at 37 degrees centigrade.

3.9.4.2 MPN test

The most probable number procedure is still widely used in sanitary bacteriology to estimate numbers of coliforms in water, milk, and other foods. Coliforms are bacteria that reside in the intestine of warm blooded mammals and are regularly excreted in the feces. They are Gram negative rods belonging to the Enterobacteriaceae family, ferment lactose and produce gas. Not all members of Enterobacteriaceae are coliforms. The MPN procedure is a statistical method based upon the probability theory. Samples are serially diluted to the point of extinction, that is, to a point where there are no more viable microorganisms. To detect the end point, multiple serial dilutions are inoculated into a suitable growth medium, and the development of some recognizable characteristic, such as acid production or turbidity, is used to indicate growth (the presence of at least one viable microorganism in the diluted sample). The pattern of positive tests (growth) in the replicates and statistical probability tables are used to determine the concentration (most probable number) of bacteria in the original sample. Statistical MPN tables are available for replicates of 3, 5, and 10 tubes of each dilution. The more replicate tubes are used, the greater the precision of the estimate of the size of the bacterial population. In this study, three tube MPN procedure is used to estimate the numbers of coliforms in a water sample. As the positive criterion for identifying coliforms, we use the ability to ferment lactose with the production of acid and gas. Acid production will be detected using bromcresol purple as a pH indicator (the change from purple to yellow = acid production) and gas production was detected using inverted Durham tubes.

3.10 Estimation of filter efficiency of suspended solids

Filter efficiency refers to the degree of removal of impurities by the filter system. Hence, the filtration efficiency has been worked out based on the removal of the suspended impurities. For this, the concentrations of suspended solids in the water before filtering and after filtering are found out as per the procedure mentioned in 3.9.2. Then efficiency of the filters has been determined by the following equation.

$$E = \frac{S_b - S_a}{S_b} \times 100 \text{ ……….. } 3.2$$

Where,

E = Efficiency of the filter, %

S_b = Suspended solids before filtering, mg/*l*

S_a= Suspended solids after filtering, mg/*l*

3.11 Discharge rate of different filter systems

3.11.1 Volumetric measurement

Discharge rate of the filter are very important to know the adequacy of the filter to allow the high discharge and short duration flow of the roof water. Outflow from the filter are collected for a known time and the volume of collected water is measured to set the discharge.

3.11.2 Coordinate method

When the discharge of the mesh filter was high, volumetric method was cumbersome, and hence, coordinate method has also been used to quantify filter discharge. Coordinate methods are used to estimate discharge from small diameter pipes discharging horizontally. In this method, it’s necessary to measure both horizontal and vertical distance from the same point at the end of the pipe to a similar point in the jet. These horizontal and vertical distance are called X and Y respectively. The coordinates are measured from the center of the jet. Discharge rate of different filters has been determined by the following equation.

$$Q = \frac{CaX\sqrt{g}}{\sqrt{2Y}} \text{…………….. } 3.3$$

Where,

Q = discharge

C = coefficient of contraction, dimensionless

a = cross-sectional area of pipe, m^2

X = x-coordinate, m

g = acceleration due to gravity, m/sec^2

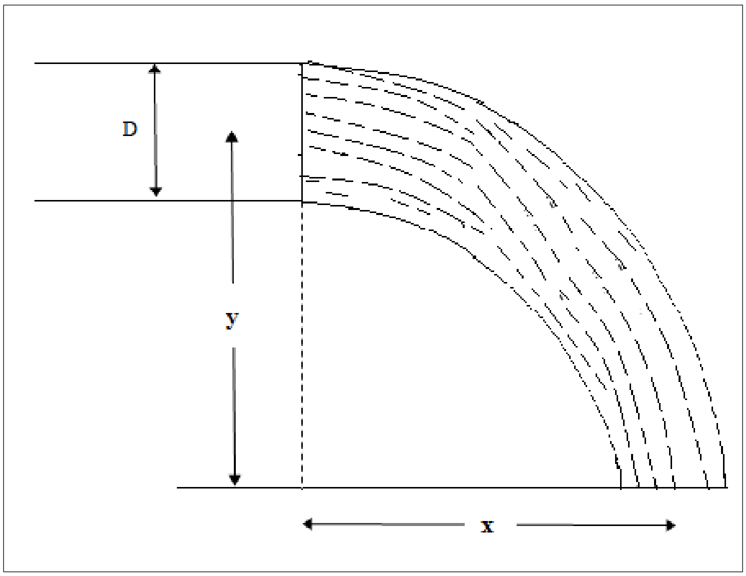

Fig 3.7 Coordinate method for measuring discharge

RESULTS AND DISCUSSIONS

CHAPTER 4

RESULTS AND DISCUSSIONS

The performance evaluation of different micromesh filters and first flush system developed for the study is described in this chapter. Micromesh filters of various mesh sizes were evaluated with regard to the purification of roof water generated from different types of roofs viz. asbestos, concrete and tiles. Performance of first flush system was tested in isolation and also in combination with micromesh filters to evaluate its impact on the purification of roof top rain water. Various water quality parameters tested are pH, EC, TDS, TSS, metals and microbial count. Direct rainwater has also been collected for several rainfall events and the quality of rain water falling through air has been analysed.

4.1 Evaluation of natural rain water quality parameters

Direct rainfall collected on 7 different days during the south west and north east monsoon period has been analysed and presented in Table 4.1 The parameters gave an insight into the quality standards of direct rainfall. While comparing the direct rainfall with the roof water, it can be seen that pH, EC and TDS of rain water are not varying considerably after its interaction with the roofs. At the same time, TSS showed very high increase (10 mg/*l* to 1000 mg/*l*).

Table 4.1Parameters for Natural rain water

Date	**06/09/14**	**13/09/14**	**25/09/14**	**11/10/14**	**17/10/14**	**23/10/14**	**30/10/14**
pH	6.9	7.1	6.9	6.8	7.1	6.9	7.2
EC (µS/cm)	95	86	83	105	87	112	91
TDS (ppm)	35.5	55	43	33.6	38	40.1	56
TSS	10	8	10	7	9	10	7

4.2 Performance evaluation of different micromesh filters

4.2.1 pH

Table 4.2 pH of roof water sample

Impurity concentrations (mg/*l*)	**Roofing materials**	**100 micron filter**		**60 micron filter**		**40 micron filter**		**25 micron filter**	
		Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
800	Asbestos	6.8 7.1	6.9 7.0 6.9	6.9 7.1	6.9 6.9 7.4	6.8 6.8	7.1 7.1 7.1	6.8 6.9	7.4 7.1 7.0
	Concrete	7.4 7.4	7.4 7.3 7.3	7.3 7.1	7.2 7.3 7.3	7.2 7.1	7.2 7.3 7.3	7.1 7.1	7.3 7.3 7.2
	Tile	7.2 7.3	7.3 7.2 7.2	7.2 7.4	7.2 7.4 7.2	7.1 7.1	7.2 7.1 7.2	7.0 7.2	7.1 7.0 7.2
600	Asbestos	6.7 7.1	6.8 7.0 6.8	6.9 7.0	6.8 6.8 7.4	6.8 6.9	7.1 7.0 7.1	6.9 6.9	7.0 7.1 7.0
	Concrete	7.3 7.3	7.2 7.3 7.3	7.3 7.2	7.2 7.3 7.3	7.2 7.1	7.2 7.3 7.3	7.1 7.2	7.3 7.2 7.2
	Tile	7.1 7.2	7.1 7.2 7.1	7.2 7.3	7.2 7.3 7.2	7.1 7.1	7.2 7.1 7.2	7.1 7.0	7.1 7.0 7.2

pH of the roof water collected from the inflow and outflow of different size micromesh systems are presented in Table 4.2. Synthetic roof water of two concentrations viz. 600 and 800 mg/*l* has been used as the incoming roof water into the filter system. There was no considerable difference between the pH values of inflow and outflow in the case of all the four filters of different mesh sizes employed in the study. However, the filtered water appeared more close to

7(neutral) in many cases. The reason for this could be that the impurities present in roof water may be changing its acid base equilibrium. 2

It can be observed that roof top rainwater and thereby the rainwater in this region is near neutral and is very well within the acceptable limit of recommendations given by WHO (6.5-8.0) and BIS (6.5-8.5) for drinking purpose. Variation of pH with respect to different roofing material was also not noticeable. The results obtained are matching with the studies reported by Thomas and Greene, 1993.

4.2.2Electrical conductivity (EC)

Electrical conductivity of the inflow and outflow of roof water from the mesh filters were analysed in the laboratory and presented in Table 4.3 and Fig 4.2. It can be seen that there was considerable reduction in electrical conductivity (10 to 15 percentage) after the filtration in the case of all the four filters. The reduction increases as the mesh size decreases from 100µ to 25µ. Though electrical conductivity is governed by dissolved impurities, the reduction in electrical conductivity indicates that the removal of suspended impurities may be causing its reduction, because the oxidation and dissolution of some of the suspended impurities may be enhancing the EC.

There is also considerable variation in electrical conductivity between roof water samples of different roofs (asbestos, concrete and tile). This variation may be due to the difference in dissolved impurities getting incorporated into the rain water from different types of roofs. Electrical conductivity was maximum in the case of concrete and minimum for tiled roof. Presence of anions in the concrete may be the reason for higher EC in the case of roof water derived from RCC roof.

Table 4.3 EC of the roof water samples

Impurity concentrations (mg/*l*)	**Roofing materials**	**100 micron filter**		**60 micron filter**		**40 micron filter**		**25 micron filter**	
		Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
800	Asbestos	139 148	105 99 95	138 141	108 95 91	146 132	91 105 88	135 136	95 89 95
	Concrete	189 174	110 115 91	188 177	125 109 95	187 171	113 116 101	177 181	108 113 92
	Tile	125 128	96 93 85	126 122	93 95 96	125 128	92 93 85	125 128	93 88 90
600	Asbestos	138 132	100 95 95	136 135	93 111 91	140 139	91 105 88	135 136	95 89 95
	Concrete	175 174	95 110 91	172 175	110 93 100	170 184	111 120 99	177 181	108 93 110
	Tile	122 125	93 93 92	122 122	92 91 92	120 128	99 86 85	121 125	83 90 89

4.3.3 Total dissolved solids (TDS)

Dissolved solids present in the inflow and outflow of the roof water samples of the various filter system are presented in Table 4.4 and Fig 4.3. TDS values were ranging from 48 to 66 ppm. There is about 15 to 20 percentage reduction in the EC values after filtration. Variations in the reduction of TDS between different mesh sizes were not well distinguishable. The reason for the reduction in TDS may be due to the reduction in suspended and other solid impurities as explained in the case of electrical conductivity. Even in the case of inflow water, the level of TDS was very low when compared to the allowable limits as given by WHO (1000 ppm). According to IS 10500-1991, desirable limit of TDS is 500ppm. For TDS also, highest values were observed for RCC roof, possibly due to the excess presence of anions in the cement concrete.

Table 4.4 TDS of the roof water samples

Impurity concentrations (mg/*l*)	**Roofing materials**	**100 micron filter**		**60 micron filter**		**40 micron filter**		**25 micron filter**	
		Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
800	Asbestos	65.9 65.2	53.4 53 53.4	65 65.5	53 53 52	64.4 64	50 53 53.5	63.6 63.8	51 50 52.5
	Concrete	68.6 66.3	55.2 55.1 55.1	66.1 66.4	55 54 54	64.8 65	54 54 54.5	64 64.2	53 53.5 54
	Tile	65.2 64.8	49.4 49 50	63.2 63.1	50 50 50	63 60.5	52 49.5 50	61.2 63	50.5 51 49.5
600	Asbestos	64.9 63.5	52.4 53.5 52	64 62.5	52.5 54 51.5	62.1 64	49.2 54 52.5	62.1 61.3	51 50 52.5
	Concrete	65.6 65.3	52.2 51.1 55.1	63.4 65.4	54 53.5 52	61.8 63	51 53 52.5	61.2 62.2	51 52.1 53
	Tile	65.2 60.8	44.4 50 50	62.8 61.3	51 51.5 46.5	64 61.5	52 48.1 49	63.2 60	51.5 50 48.95

4.2.4 Total suspended solids (TSS)

The results of the analysis of suspended matter impurities in the inflow and outflow of the filter system are shown in the Table 4.5 and Fig 4.4. In the case of inorganic suspended matter, the allowable limit as per WHO and BIS is 500 mg/*l*. However, in the case of organic impurities, the allowable limit is in the range of 50 to 200 mg/*l*, a value very near to a zero. The level of suspended matter impurities present in roof water, which is mainly organic in nature, was observed to be of the order of 400 to 1000 mg/*l*. This value is very high from the drinking water quality standards. Hence, the main challenge of roof water harvesting is the removal of organic suspended matter impurities.

While comparing the impurity level in the inflow and outflow, it can be seen that about 90 percentage of suspended impurities were removed by the mesh filter developed. For 100 and 60 micron filters, the TSS values of the filtered water is about 60 mg/*l* against an average inflow concentration of 400 mg/*l*. corresponding values for 40 and 25 micron filters, were near to 40 mg/*l*. The results, indicate that there is further scope for reduction of mesh size, if material is available.

Table 4.5 TSS of roof water samples

Impurity concentration (mg/l)	**Mesh size**	**Roof material**	**Weight of filter paper (mg)**	**Weight of filter paper with sample of inflow after drying (mg)**	**Concentration of suspended solids in inflow (mg/l)**	**Weight of filter paper with sample of outflow after drying(mg)**	**Concentrati-on suspended solids in outflow (mg/l)**
800	100	Asbestos	770	789	380	773	60
		Clay tile	770	790	400	773	60
		Concrete	770	791	420	773	60
	60	Asbestos	770	789	380	772.5	50
		Clay tile	770	792	440	773	60
		Concrete	770	788	360	772	40
	40	Asbestos	770	787	340	773	60
		Clay tile	770	788	360	772	40
		Concrete	770	787	340	772	40
	25	Asbestos	770	786	320	772	40
		Clay tile	770	787	340	772	40
		Concrete	770	789	380	772	40
	100	Asbestos	770	787	340	772.5	50
		Clay tile	770	793	460	773	60
		Concrete	770	789	360	773	60
	60	Asbestos	770	790	400	773	60
		Clay tile	770	788	360	772.5	50
		Concrete	770	792	420	773	60
		Asbestos	770	787	340	772	40

Table 4.5 Continued

600	40	Clay tile	770	788	360	772	40
		Concrete	770	787	340	773	60
	25	Asbestos	770	789	380	772	40
		Clay tile	770	786	320	772	40
		Concrete	770	787	340	772	40

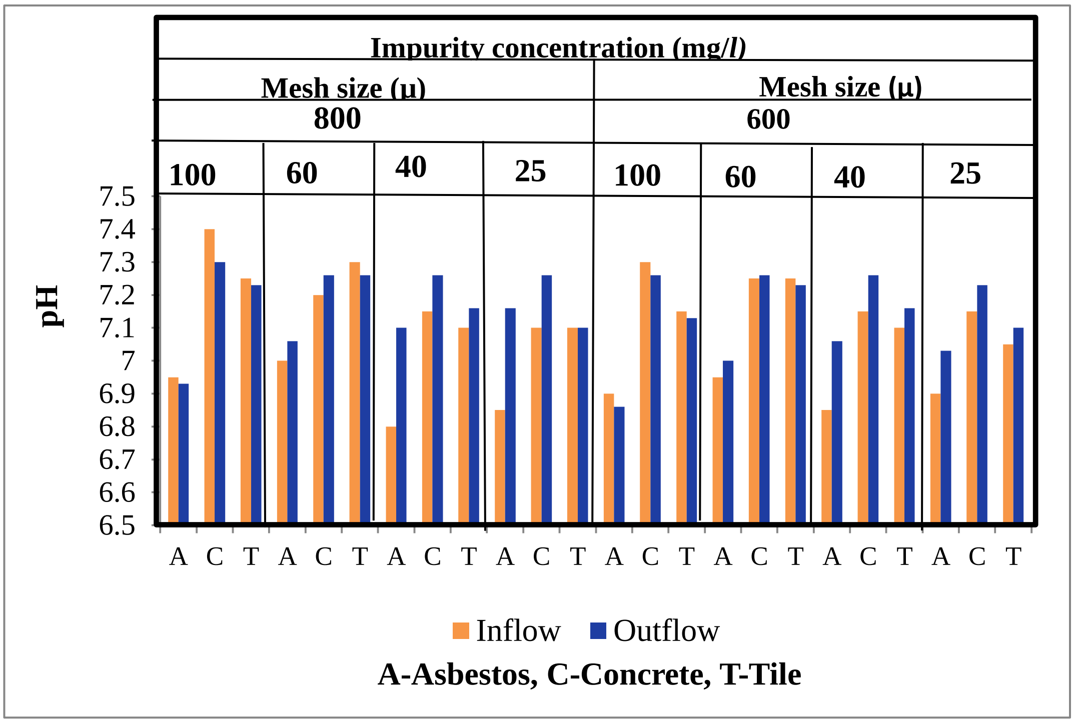

Fig. 4.1 pH of roof water samples

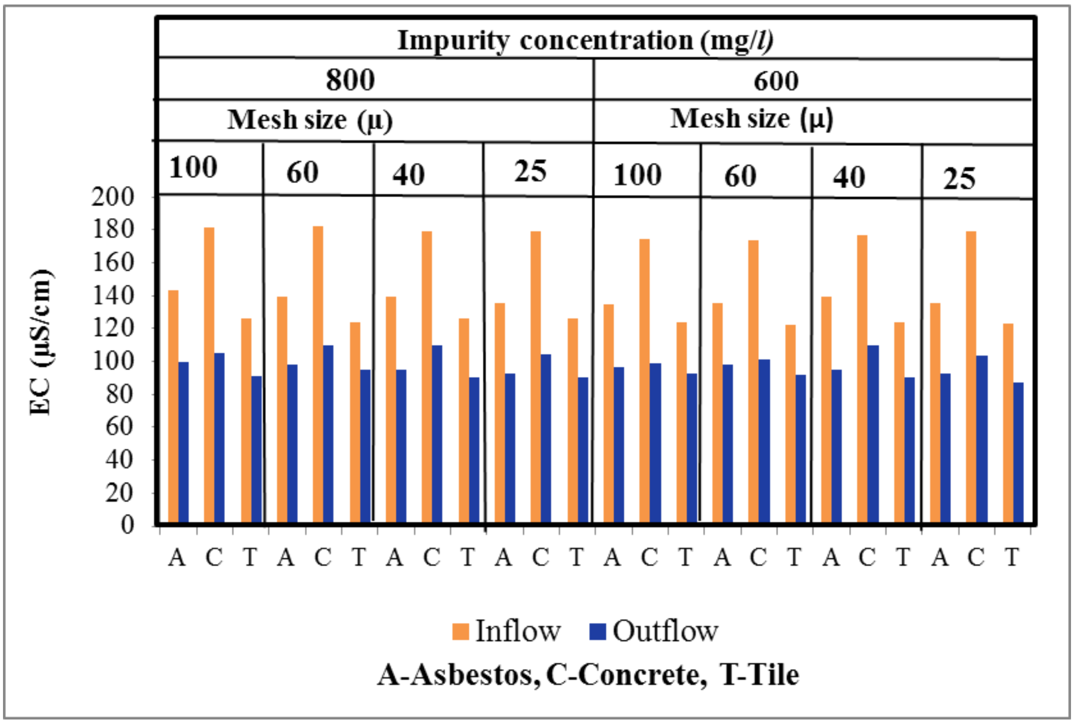

Fig 4.2 EC of roof water samples

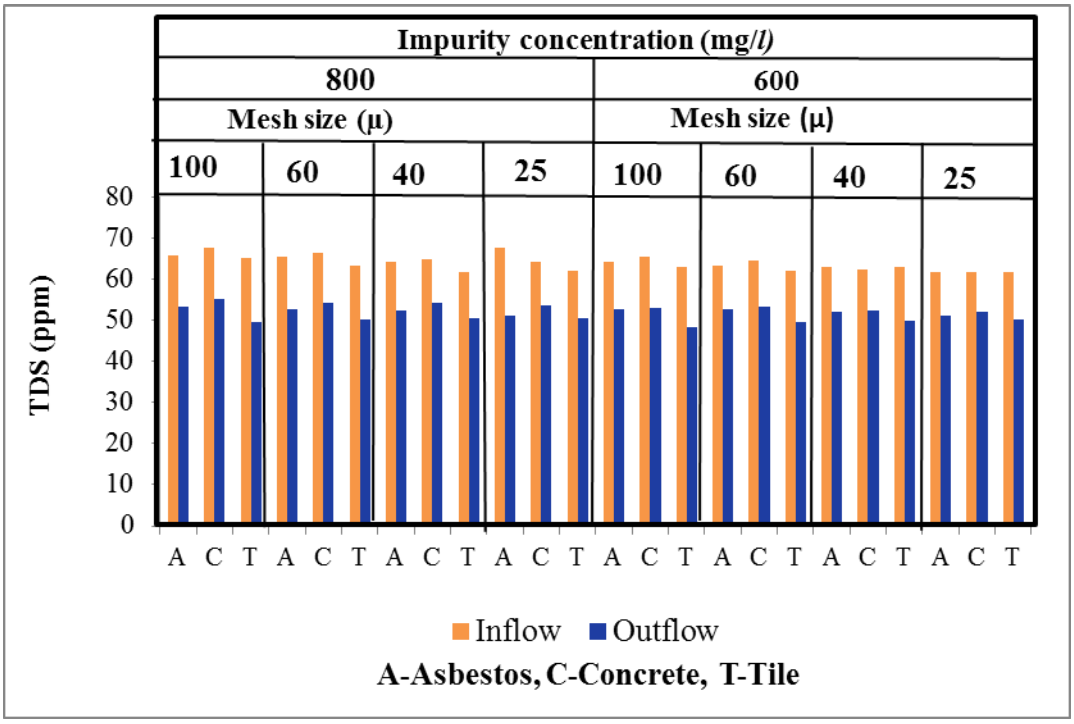

Fig 4.3 TDS of roof water samples

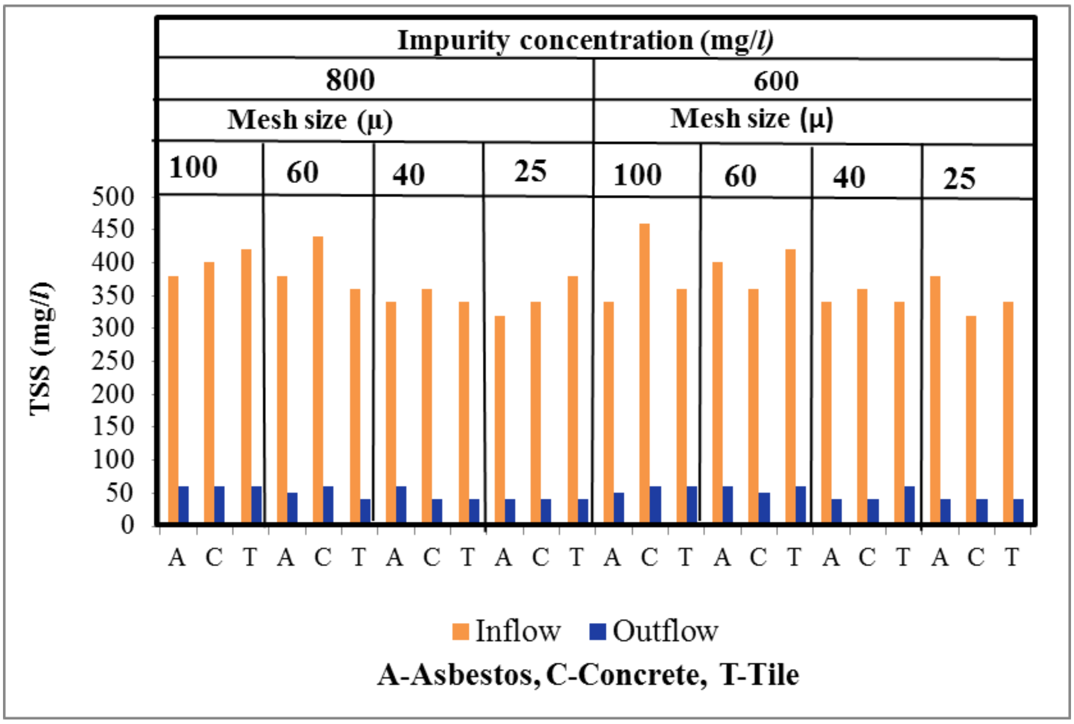

Fig 4.4 TSS of roof water samples

4.2.5 Metal concentration

The inflow and outflow of the roof water samples of the mesh filters under study were analysed and quantified for the presence of metals. The analyses were undertaken at the Radio Tracer Laboratory of Kerala Agricultural University, Thrissur. A total of 8 metals viz. copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) were analysed, for which facilities were available. Tests were carried out only for 100 and 60 micron meshes due to the financial constraints in meeting the cost of analyses. The results are given in Fig 4.5 to Fig 4.12. The average concentration of copper was 0.049 mg/l for the concrete, 0.038mg/*l* for the clay tiles and 0.054 mg/*l* for the asbestos roof for the collected inflow samples. Corresponding metal concentration for the mesh filtered roof water were 0.036 mg/*l*, 0.025 mg/*l*, and 0.049 mg/*l*. There was clear indication of decline in copper concentration after the mesh filtration. Among the roofs, asbestos yielded maximum copper concentration and minimum was for concrete. The source of copper could be the atmospheric and the roofing material. The concentration of copper was within the allowable limit as per the norms of WHO (2 mg/*l*) and BIS (0.05 mg/*l*). Clay tiles are highly porous, and the lower copper concentrations observed in its case could be the result of pollutants getting trapped within the porous space. The concentration of zinc was highest in the case of asbestos and least in tile roof (0.018 mg/*l).* The source of zinc could also be atmosphere and the roofing material. WHO guideline of zinc in drinking water is 3 mg/*l*. Iron concentration peaked in concrete roof water (0.22 mg/*l*). Here also, tile roofs gave minimum value for iron concentration. Concentration of this metal is quite lower than the WHO and BIS upper limit of 0.2 and 0.3 mg/l respectively for potable water. About 10 to 15 percentage reduction is seen after filtration for all the three metals (Cu, Zn, Fe).

The average sodium (Na), calcium (Ca) and manganese (Mn) concentrations of the asbestos roof water (0.27 mg/*l*, 0.72 mg/*l*and 0.045 mg/*l*) were considerably higher than those of the other two roofing materials in the inflow samples. The metals also showed decline (10 to 20 percentage) after filtrations with 100 and 60 micron mesh filters. The concentration of potassium was higher in the inflow samples of clay tiles (0.8 mg/*l*) than asbestos and concrete roofing materials. The raw materials of clay tiles viz. soil may be the reason for the increased presence of potassium in clay tiled roof water. After filtration with mesh filters, reduction in concentration can be observed in the case of these metals (Na, Ca, Mn, K, Mg).

The above results can be summarized that the metallic concentration of roof water samples were well within the allowable limit for drinking, as recommended by WHO and BIS. After filtration using upward flow meshes filters, there is reduction in the concentration of these metals of the order of 10 to 20 percentage. Filtration using further smaller size meshes may result in the better removal of these metals.

Similar studies were conducted by different researchers on quality of roof harvested rainwater by Mentez *et al*., 2014. The results of these studies were matching with the above results of metal concentration in roof water.

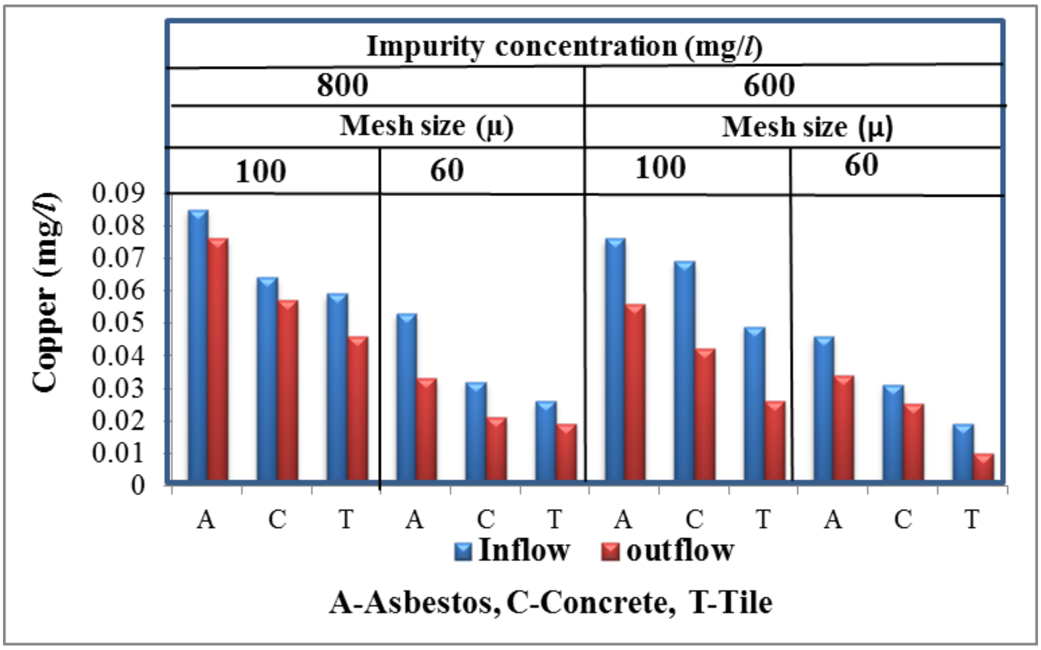

Fig. 4.5 Copper concentrations of samples

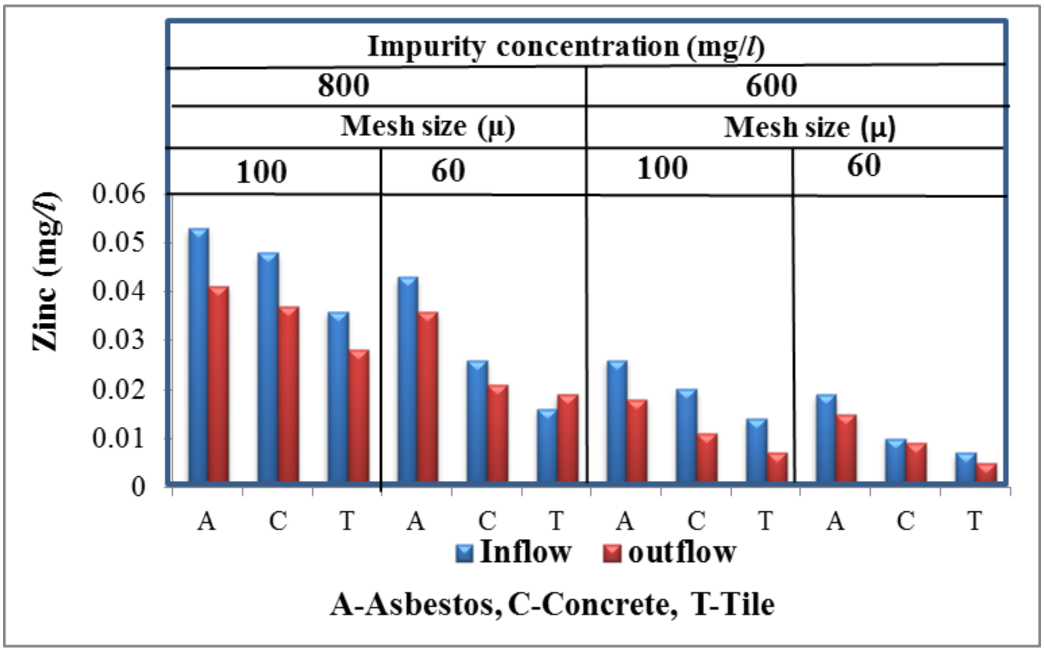

Fig. 4.6 Zinc concentration of samples

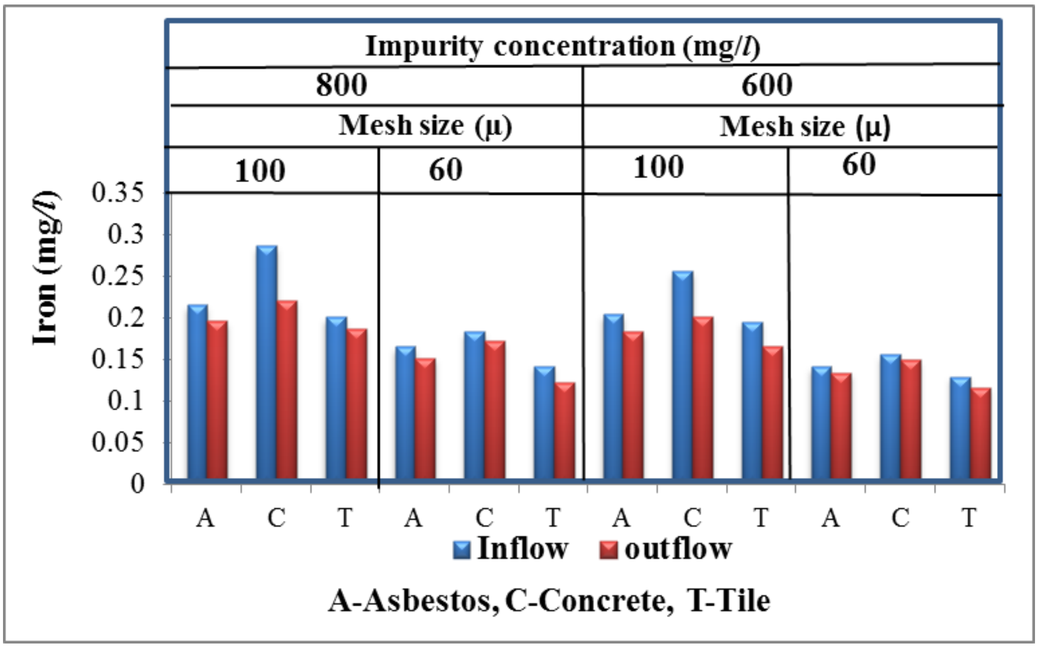

Fig. 4.7 Iron concentration of samples

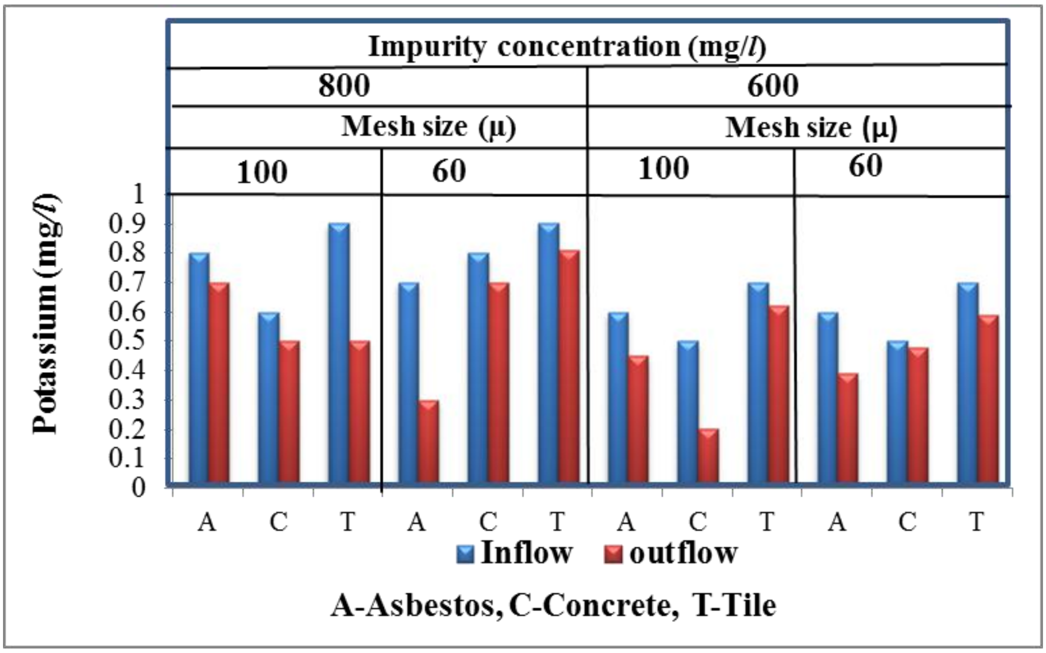

Fig. 4.8 Potassium concentration of samples

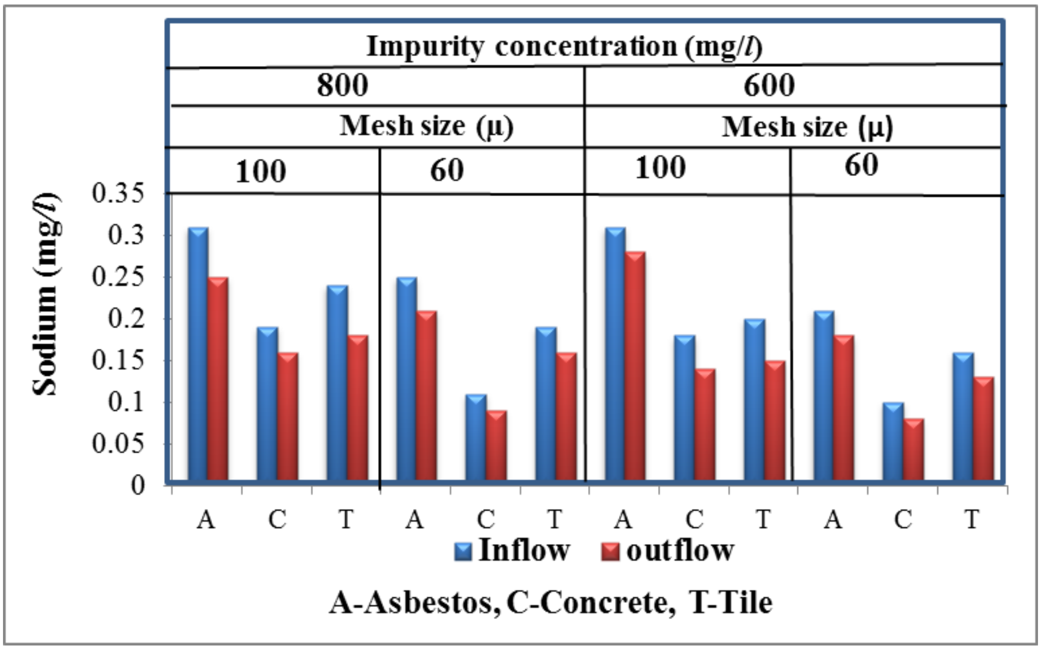

Fig. 4.9 Sodium concentration of samples

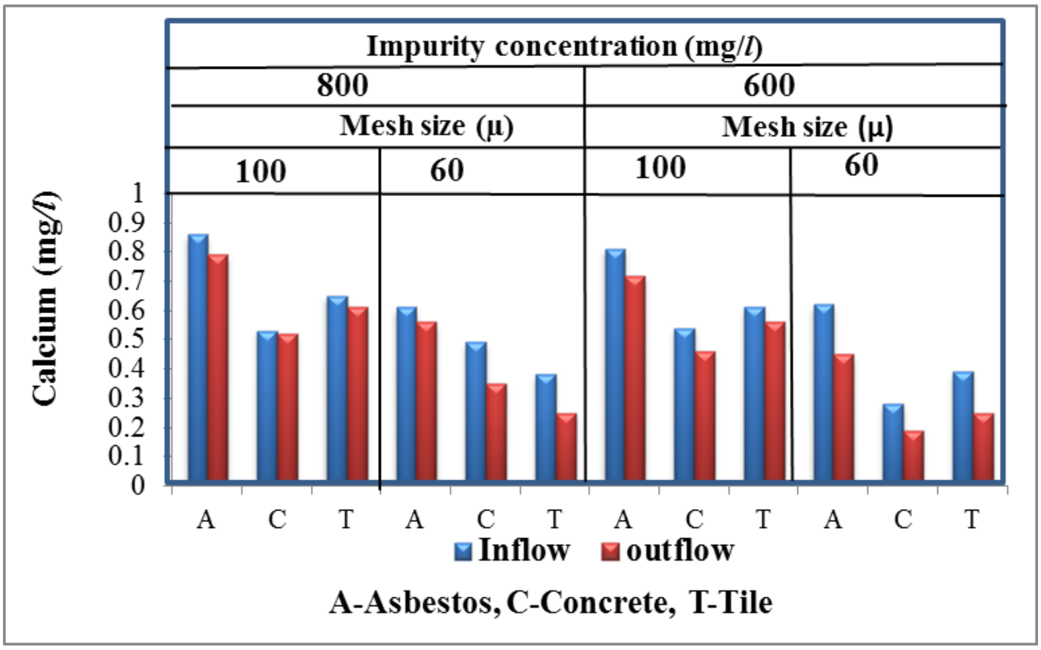

Fig. 4.10 Calcium concentration of samples

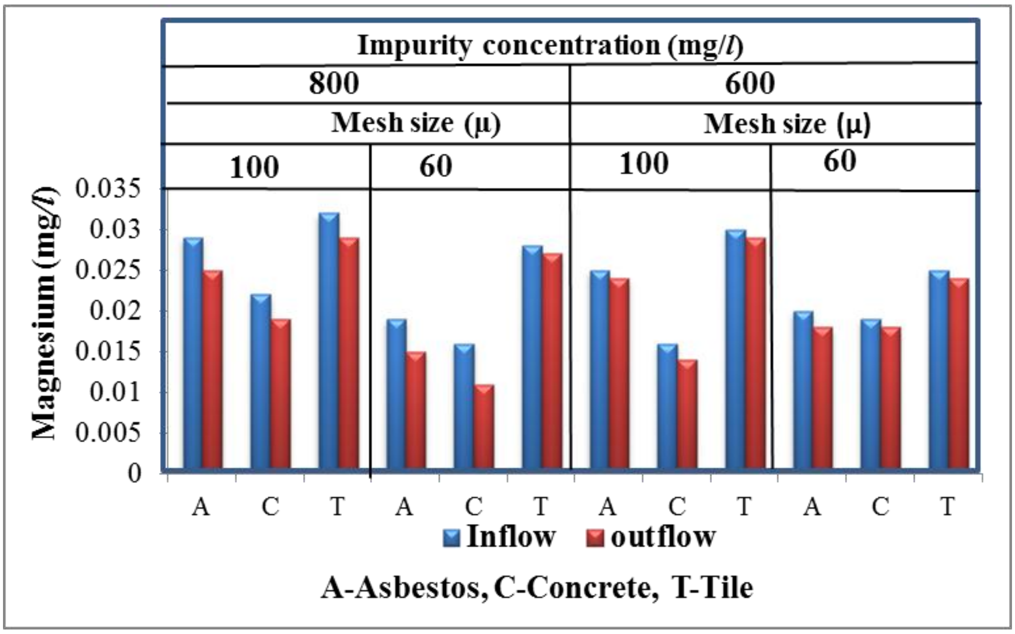

Fig. 4.11 Magnesium concentration of samples

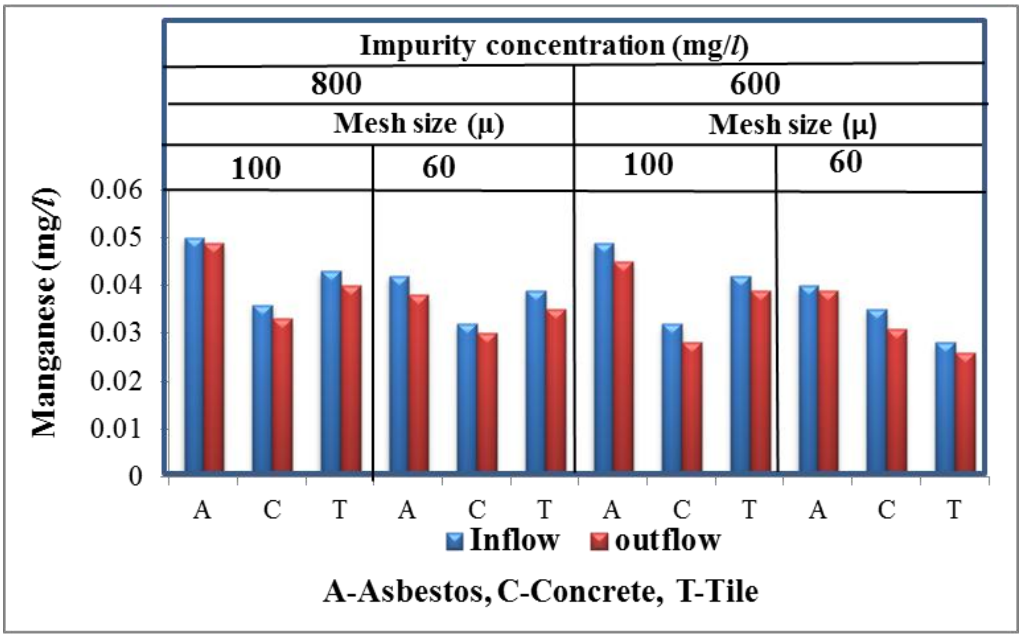

Fig. 4.12 Manganese concentration of samples

4.2.6 Microbiological parameters

Table 4.6 Microbiological parameters of roof water samples

Mesh size	Roofing materials	Total bacteria (10^5cfu/ml)		Fungi (10^2cfu/ml)		Actinomycetes (10^3cfu/ml)		Total coliform count (MPN Index)	
		Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
100	Asbestos	83	30	5	2	4	2	10	7
	Concrete	123	107	2	1	7	4	14	12
	Tile	94	91	5	3	5	3	9	7
60	Asbestos	76	62	3	1	3	2	7	5
	Concrete	73	38	5	1	4	2	8	6
	Tile	62	48	3	1	2	1	6	4
40	Asbestos	28	22	2	1	1	0	4	2
	Concrete	49	36	3	0	3	0	6	4
	Tile	35	29	1	0	2	0	5	3
25	Asbestos	18	9	1	0	1	0	3	2
	Concrete	22	20	3	0	1	0	5	3
	Tile	20	17	1	0	1	0	4	2

To determine the suitability of roof harvested rainwater as a source of drinking water, the samples were analysed for total bacteria, fungi, actinomycetes, total coliform and E.*coli*. The tests were carried out at the microbiology lab of college of Horticulture, KAU, Thrissur. In all the cases, highest number of bacterial pathogens was found in concrete and tiled roof samples, most likely due to the greater presence and growth of lichens, mosses and plants on this roofing material. Filtration has shown considerable reduction in their counts. Fungi and actinomycets counts were in the range of $3x10^2$ to $5x10^2$cfu/m*l* and $3x10^3$ to $6x10^3$cfu/m*l* respectively. After the filtration, their counts have come down by about 50percentage. Fungi and actinomycetes were completely removed in the case of 40 and 25 micron filters.

Similar studies were conducted by different researchers on quality of roof harvested rainwater with different roofing materials. The microbial concentration obtained here was matching with the study reported by Thomas and Greene, 1993.

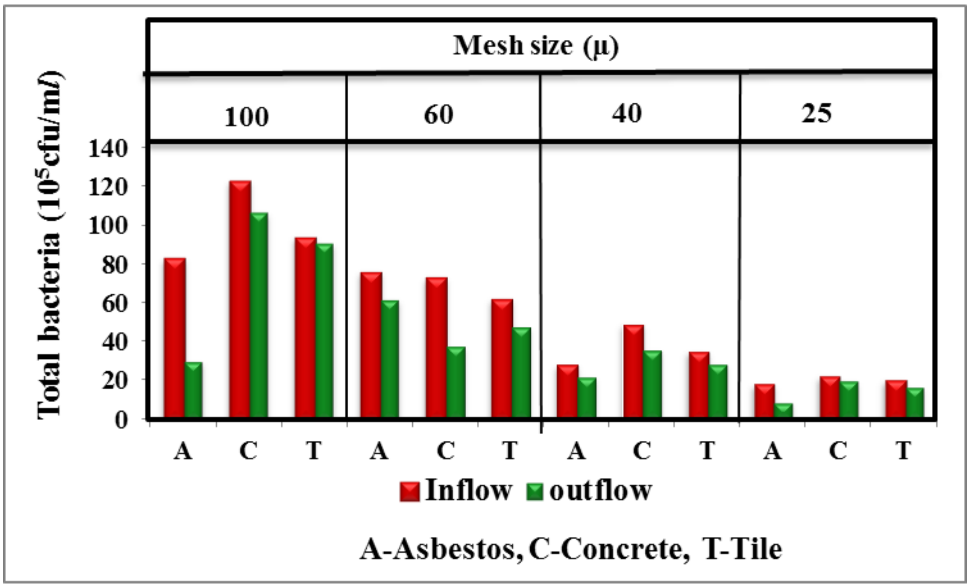

Fig. 4.13 Total bacterial concentration in roof water samples

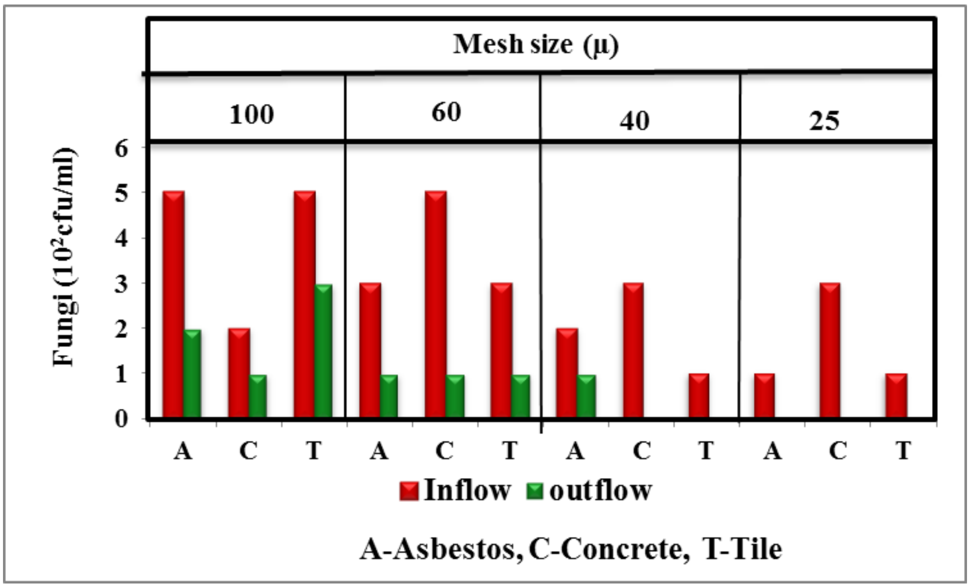

Fig. 4.14 Fungi concentration in roof water samples

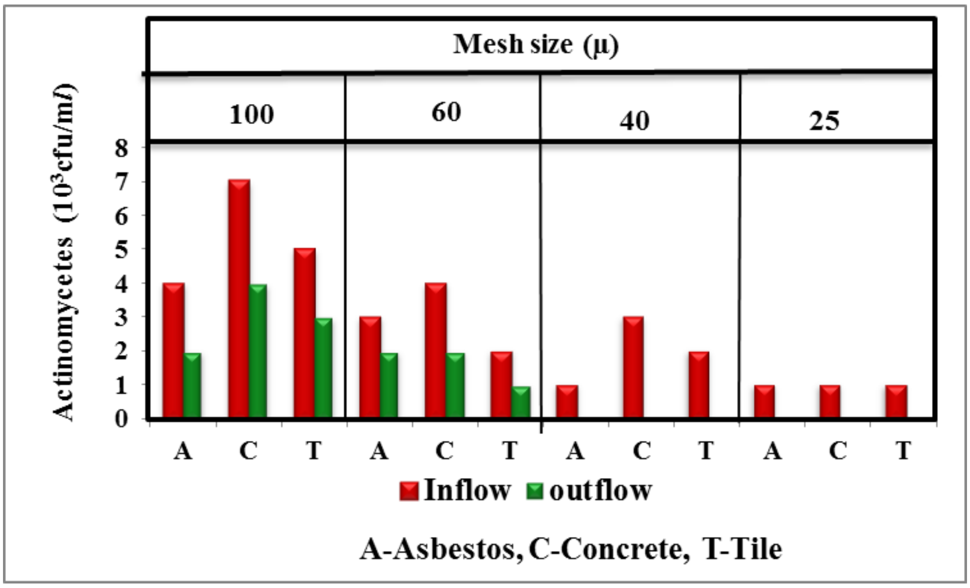

Fig. 4.15 Actinomycete concentration in roof water samples

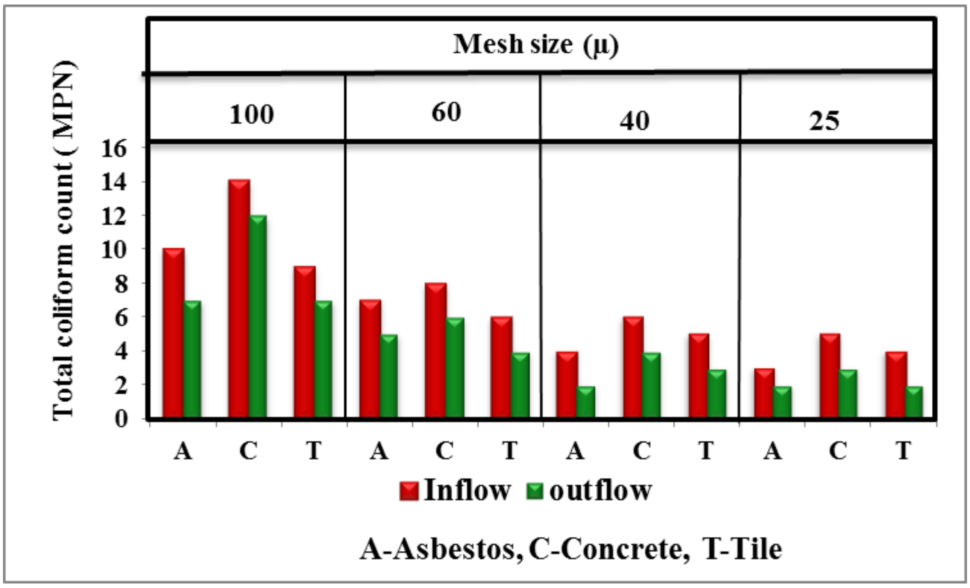

Fig. 4.16 Total coliform count by MPN index

4.3 Performance evaluation of first flush

Performance evaluation of the first flush systems has been done by connecting it at the inlet side of the filter system. The entire experiment adopted for the evaluation of the filter system was done in the case of first flush system also. Roof water samples were analysed for the water quality parameters of pH, EC, TDS and TSS by repeating the experiment by connecting the first flush in series with the filter system on its inlet end.

4.3.1 pH

The pH of the roof water samples collected from the inlet and outlet end of the first flush cum filter system are presented in Table 4.7 and Fig 4.17. No markable changes were seen in the roof water inflow and outflow samples when compared to that of the ‘only mesh filter’ case.

Table 4.7 pH of water samples for first flush cum filter system

Impurity concentrations (mg/*l*)	**Roofing materials**	**100 micron filter**		**60 micron filter**		**40 micron filter**		**25 micron filter**	
		Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
800	Asbestos	7.1 7.2	7.3 7.2 7.1	7.2 7.1	7.2 7.2 7.1	7.0 7.2	7.0 7.2 7.2	7.1 7.0	7.2 7.1 7.1
	Concrete	7.3 7.4	7.4 7.5 7.4	7.2 7.4	7.3 7.3 7.2	7.3 7.3	7.3 7.2 7.3	7.3 7.2	7.3 7.3 7.2
	Tile	7.3 7.2	7.3 7.3 7.2	7.2 7.2	7.3 7.2 7.3	7.2 7.2	7.3 7.3 7.2	7.2 7.2	7.3 7.2 7.3
600	Asbestos	7.1 7.0	7.2 7.2 7.1	7.2 7.1	7.3 7.2 7.1	7.0 7.2	7.0 7.2 7.2	7.1 7.0	7.2 7.1 7.1
	Concrete	7.3 7.4	7.3 7.5 7.4	7.2 7.4	7.4 7.2 7.2	7.3 7.3	7.3 7.2 7.3	7.3 7.2	7.3 7.2 7.3
	Tile	7.2 7.2	7.3 7.3 7.2	7.2 7.2	7.3 7.2 7.3	7.2 7.2	7.3 7.3 7.2	7.2 7.2	7.2 7.2 7.3

4.3.2 Electrical conductivity

The EC values of the inflow and outflow roof water samples are shown in Table 4.8 and Fig 4.18. The results were not appreciably different from that of filter alone case. Hence, it is to be inferred that the addition of first flush is not making any markable impact on the water on the water quality parameter, EC of roof water.

Table 4.8 EC of roof water samples for first flush system

Concentrations (mg/l)	**Roofing materials**	**100 micron filter**		**60 micron filter**		**40 micron filter**		**25 micron filter**	
		Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
800	Asbestos	149 135	105 99 95	141 139	93 103 98	146 132	102 91 90	129 136	88 96 94
	Concrete	166 182	116 92 115	176 187	125 109 95	172 161	113 116 101	167 173	92 103 92
	Tile	127 130	101 92 93	122 132	90 95 91	125 128	92 93 85	122 128	93 76 86
600	Asbestos	129 131	100 95 95	136 135	93 111 91	140 139	91 105 88	135 136	95 89 95
	Concrete	165 170	95 110 91	172 175	110 93 100	169 179	111 120 99	177 181	108 93 110
	Tile	120 126	85 88 92	119 120	88 93 86	120 128	86 81 90	119 120	82 85 81

4.2.3 Total dissolved solids

The results of TDS are tabulated and presented in Table 4.9 and Fig 4.19. In the case of TDS, too, the results were not appreciably different from of ‘filter only’ case.

Table 4.9 TDS of water samples for first flush system

Impurity concentrations (mg/l)	Roofing materials	100 micron filter		60 micron filter		40 micron filter		25 micron filter	
		Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
800	Asbestos	64.9 65.3	52.4 53 53.4	65 65.5	52.5 51.9 51.8	64.4 64	51.5 51 51.5	62 62.5	50 50 52.5
	Concrete	67.6 65.4	53.2 54.1 54.2	66.1 66.4	53.5 54.2 53.6	64.8 65	52 52 51.5	63 63.5	52 50.5 54
	Tile	63.2 63.2	48.4 49 50	63.2 63.1	49.2 48.6 49.9	63 60.5	48.9 49.5 47	61.2 61	49.5 51 49.5
600	Asbestos	62.1 60.5	50.4 53.5 54	63.1 60.5	52.5 54 51.5	62.1 64	49.2 54 52.5	62.1 61.3	51 50 52.5
	Concrete	65.6 65.3	52.2 52.1 54.1	63.4 64.1	53 53.5 53	60.8 64	50 52 52.8	61.4 60.3	51 50.1 53
	Tile	65.2 60.8	48.4 51 49	63.8 60.3	50 50.5 48.5	60 61.1	50 47.1 48	61.6 60.1	51.4 50.1 47.2

4.3.4 Total suspended solids

The results of the analysis of the TSS of the inflow and outflow samples of the first flush and filter combination is given in Table 4.10 and Fig. 4.20. There is considerable reduction in the TSS of outflow samples compared to the ‘only filter’ case. The reduction is about 30percentage and it can be observed for all filters of different mesh sizes. This reduction of TSS can be attributed to the positive contribution of the first flush system. Hence, a first flush mechanism may be recommended in roof water purification system.

Table 4.10 TSS of first flush system

Impurity concentration (mg/*l*)	Mesh size	Roof material	Weight of filter paper (mg)	Wt. of filter paper with sample of inflow after drying (mg)	Concentration of suspended solids in inflow (mg/*l*)	Wt. of filter paper with sample of outflow after drying(mg)	Concentration suspended solids in outflow (mg/*l*)
800	100	Asbestos	770	776	120	772	40
		Clay tile	770	775	100	771.5	30
		Concrete	770	777	140	772	40
	60	Asbestos	770	775	100	771.5	30
		Clay tile	770	776	120	771	20
		Concrete	770	776	140	772	40
	40	Asbestos	770	775	100	771.5	30
		Clay tile	770	774	80	771	20
		Concrete	770	775	100	772	40
	25	Asbestos	770	774	80	770.5	10
		Clay tile	770	774	80	771	20
		Concrete	770	775	100	771.5	30
600	100	Asbestos	770	775	100	771	20
		Clay tile	770	774	80	772	40
		Concrete	770	775	100	772	40
	60	Asbestos	770	775	100	771	20
		Clay tile	770	773	60	772	40
		Concrete	770	776	120	772	40
	40	Asbestos	770	773	60	771.5	30
		Clay tile	770	774	80	771	20
		Concrete	770	774	80	772	40
	25	Asbestos	770	773	60	770.5	10
		Clay tile	770	774	80	770.5	10
		Concrete	770	773	60	771	20

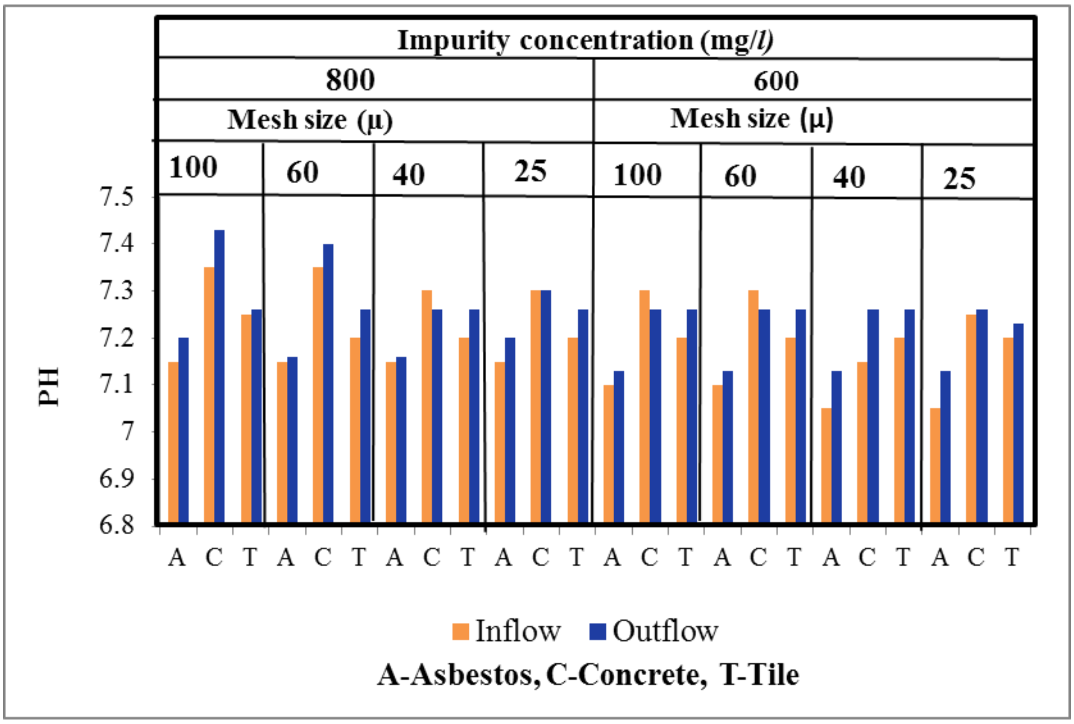

Fig 4.17 pH of roof water samples for first flush system

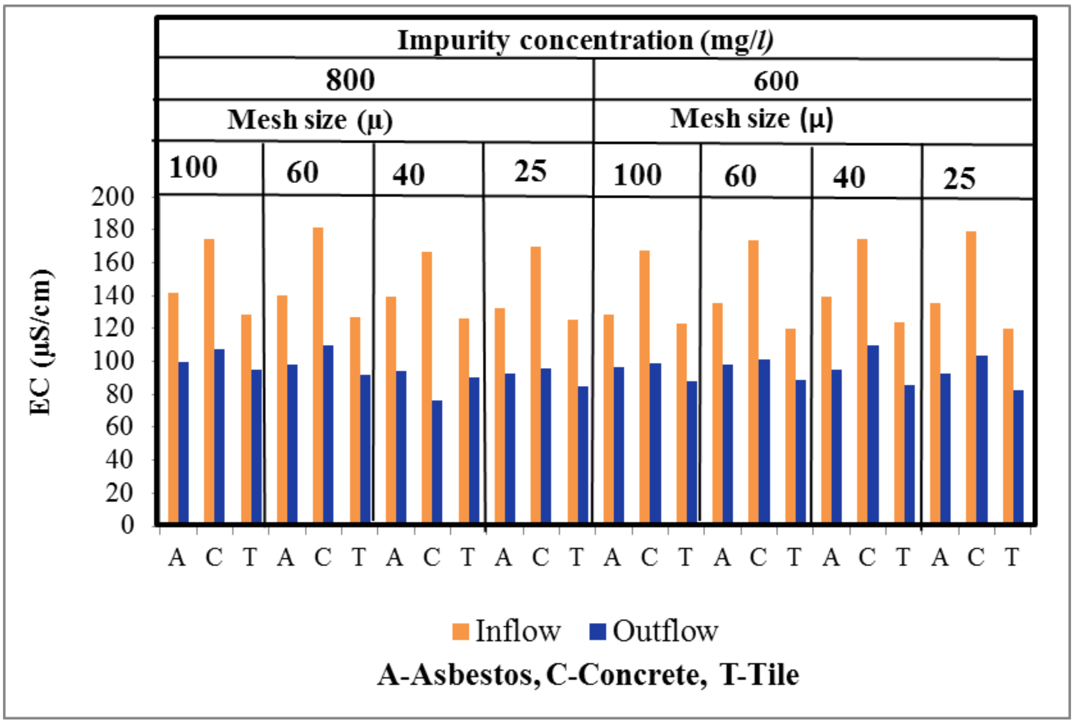

Fig 4.18 EC of roof water samples for first flush system

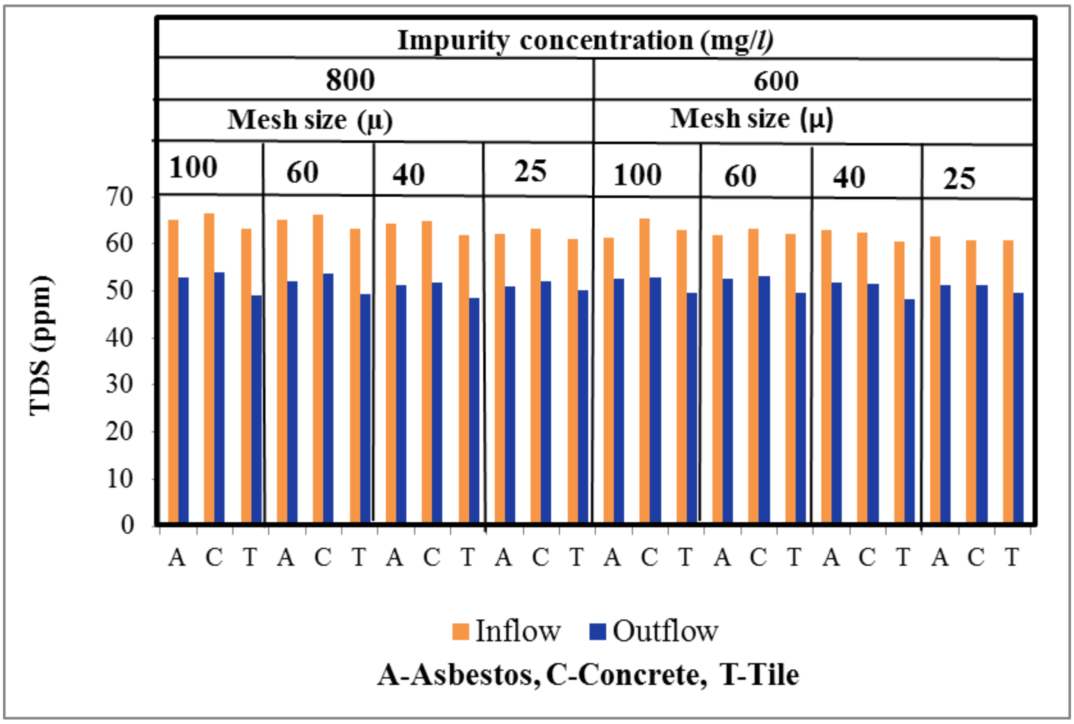

Fig 4.19 TDS of roof water samples for first flush system

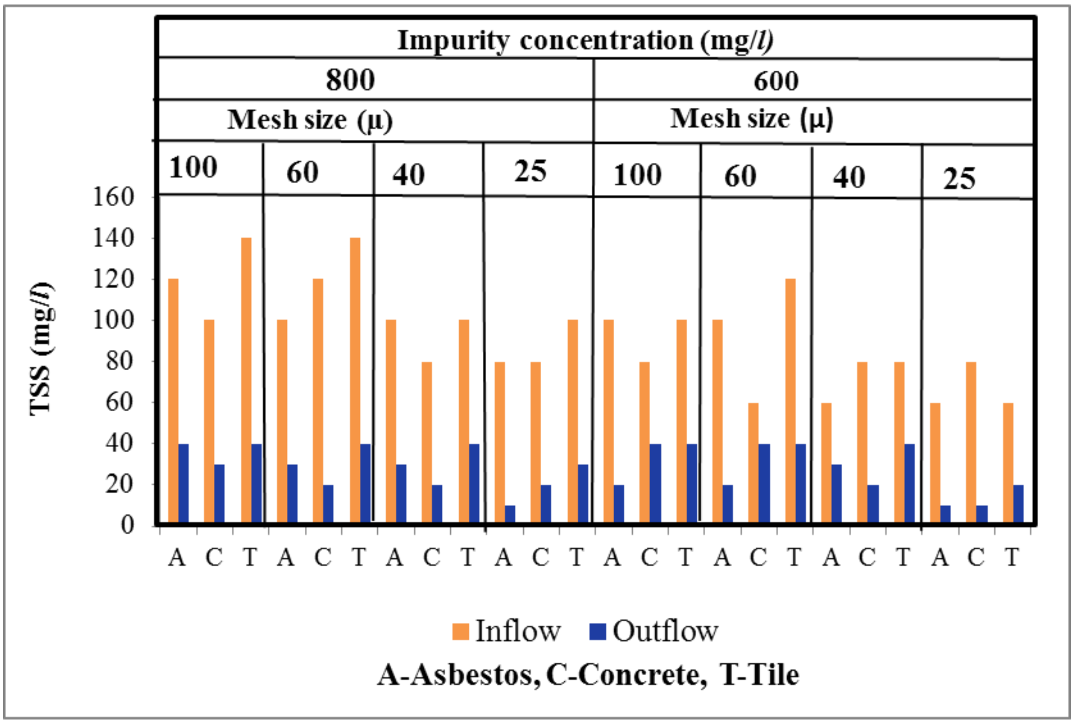

Fig 4.20 TSS of roof water samples for first flush system

4.4 Filtration Efficiency of suspended solids

Table 4.11 Filtration efficiency of different filters

Impurity concentrations (mg/l)	Mesh size	Roof material	Suspended solids before filtering (mg/l)	Suspended solids after filtering(mg/l)	Efficiency (%)	Mean average Efficiency (%)
800	100	Asbestos	380	60	84.2	84.6
		Clay tile	400	60	85	
		Concrete	420	60	85.7	
	60	Asbestos	380	50	86.84	86.2
		Clay tile	440	60	86.36	
		Concrete	360	40	88	
	40	Asbestos	340	60	86.36	87.53
		Clay tile	360	40	88	
		Concrete	340	40	88.23	
	25	Asbestos	320	40	87.5	88.4
		Clay tile	340	40	88.23	
		Concrete	380	40	89.47	
600	100	Asbestos	340	50	85.29	84.6
		Clay tile	460	70	84.78	
		Concrete	360	60	83.3	
	60	Asbestos	400	60	85	86.2
		Clay tile	360	50	86.11	
		Concrete	420	60	85.7	
	40	Asbestos	340	40	88.23	87.53
		Clay tile	360	40	88	
		Concrete	340	60	86.36	
	25	Asbestos	380	40	89.47	88.4
		Clay tile	320	40	87.5	
		Concrete	340	40	88.23	

The primary function of the mesh filters are the removal of suspended matter. Along with the removal of suspended impurities it also helps in reducing the presence of other undesirable material and improves the overall quality of potability of roof water. Hence, the filtration efficiency of the mesh filters was evaluated from the point of removal of suspended impurities. It is presented in Table 4.11 and Fig 4.21 and it shows very high values in the case of all the four filters. As expected, when the mesh size decreases, the efficiency increases and the highest efficiency of 88percentage is obtained for 25 micron filter. It is expected that further reduction in mesh size will improve the filtration efficiency to still higher levels.

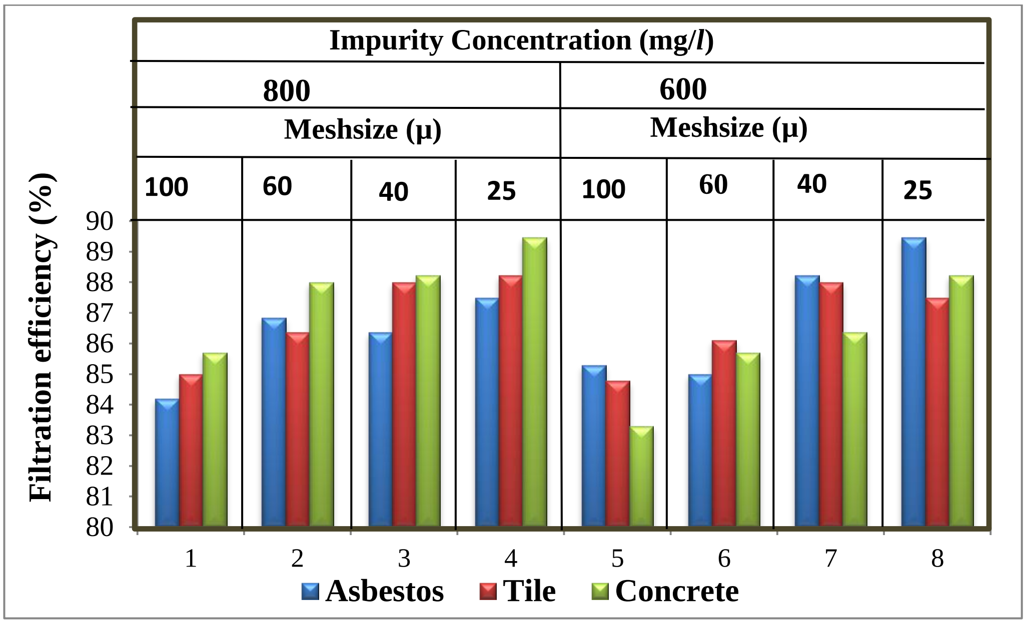

Fig.4.21 Filtration efficiency of filters

4.5 Discharge rate of different filter systems

Discharge rate of the different filters are important in the case of roof water harvesting. As rain last for shorter intervals, the incoming roof water to the filter system also will be for short duration but with high discharge. Filtration is taking place under gravity flow, hence, checking the filtration rate assumes great significance. Also this information will help others in designing mesh filters to suit to their requirement.

The discharge rates of different filters are presented in Table 4.12. Even 25 micron filter has a discharge of 1.09 *l*/s under a head of flow of 1.5m. Filtration rate per unit area of mesh has also been worked out. This discharge rate is sufficient to contain the roof water inflow expected for high rainfall intensities.

Table 4.12 Discharge rate of different filters

Mesh size (μ)	Vertical height (cm)	Horizontal distance (cm)	Discharge rate (l/s)	Discharge rate per mesh area (l/s/m^2)	Mean average discharge (l/s/m^2)
100	151	87 88	1.64 1.66	--	--
60	151	59 59.5 56.5 58.5	1.11 1.123 1.066 1.104	247.21 250.11 237.41 245.87	245.15
40	151	29 23 23 23.5	0.547 0.432 0.432 0.462	224.82 177.55 177.55 189.88	192.45
25	151	60 55 60 57	1.132 1.038 1.132 1.0762	194.87 178.68 194.87 185.26	188.42

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The enormity of water crisis and the need of water conservation to remedy the situations are well understood and need no over emphasising. Government agencies across the globe are introducing policies to promote increased use of directly captured rainwater, as a supplementary source of drinking water. The Government of Kerala has introduced legislation making roof top rainwater harvesting mandatory in all newly constructed buildings in the state. Though roof top rain water harvesting has immense potential in solving the domestic water crisis, it is crippled with the present day sand and gravel purification system which is not easy to clean and maintain. Although studies have been initiated with alternative purification methods with mesh filters, it needs further modification and improvisation. Under this circumstance, this M.Tech research has been taken up with the following objectives.

- To develop an appropriate first flush system for domestic roof water harvesting.
- To develop an efficient filter system for roof water harvesting.

The study included the development and evaluation of four different sizes of upward flow mesh filters of 100, 60, 40 and 25 micron and a first flush or foul flush system. Roof water samples were collected from the inlet and outlet side of the filter system and analysed for pH, EC, TDS, TSS, metal concentrations and microbial quality. Roof water generated from three different roofs viz. asbestos, concrete and clay tiles were used in the study to assess their quality and to evaluate the performance of the filters and first flush system.

The study revealed that pH of the generated water from different roofs was within the limit of 6.8 to 7.3 and not showing variation with respect to type of roofs. Electrical conductivity of the roof water were within the range of 85 to 189 µs/cm, which was with in the acceptable limit of drinking water standards. Considerable variations were noticed in the case of electrical conductivity between the types of roofs. Micromesh filtration was found to reduce the electrical conductivity values by about 10 to 15 percentage. TSS was within the rage of 40 to 60 mg/*l* and filtration reduced the TSS values to about 10 percentage. The TSS values were different for various roofing types. Major parts of suspended materials were organic matter derived from mosses, algae and other vegetative growth. It showed variation between the roofs. The TSS presence was very higher than the permissible limits set by WHO and BIS. Micromesh filtration was able to remove 90 percentage of the suspended impurities. Metal concentrations viz. copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) were tested for roof water and result showed that concentrations of all the 8 metallic elements were within the permissible limit of potable water. Mesh filtration has shown slight reduction (10 to 15 percentage) in their concentration. Microbial qualities of water (total bacteria, fungi, actinomycete, total coliform and E.*coli*) showed that their count were within the permissible limit. Micromesh filtration yielded considerable reduction (about 5 to 100 percentage) in their counts. Discharge rate of micromesh filtration was varying from 0.4 to 1.6 *l*/s and was sufficient to handle high intensity of rains.

The first flush system was able to collect 20*l* of initial most impure water generated and was capable of diverting it from the main storage of purified roof water. It was not permitting the mixing up of highly impure and relatively cleaner water. Use of first flush in combination with mesh filters showed beneficial results in removing the suspended impurities (about 20 percentage decrease).

The study leads to the following conclusions;

1. Direct rainwater qualities of Tavanur region with regard to pH, electrical conductivity, TDS and TSS are very much meeting the quality standards of WHO and BIS for potable water.
2. EC, TDS and TSS of rainwater increases considerably after its interaction with roof top surfaces. EC and TDS of roof top water is also within the potable limit.
3. Addition of suspended load by rooftop is mainly of organic in nature and its load far exceeds the permissible limits of potable water.

4. Reduction of suspended organic load in the roof water by the mesh filter was about 88 percentage and thereby attains drinking water standards. This result can be cited as a notable achievement of this study.
5. Metal concentration and microbial limit of rooftop rainwater were within the acceptable limit of drinking water standards.
6. Mesh filter reduced the EC, TDS, metal concentrations by 10 to 20 percentage and microbial load by 50 to 100 percentage.
7. First flush system in combination with the mesh filter further reduces the organic suspended load in rooftop rainwater.
8. Discharge rate of mesh filters were very high, even for 25 µ mesh, and hence there is scope for reducing the mesh size of filters to get higher filtration efficiency.

Future scope of work;

1. Mesh size lower than 25 µ may be employed to get higher filtration efficiency of suspended impurities.
2. Various means of automation of first flush system may be probed.

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APPENDIX I

Concentrations (mg/l)	Mesh size	Roof material	Inflow/ outflow	Parameters							
				Cu	Zn	Fe	Mn	Ca	Mg	Na	K
800	100	Asbestos	Inflow	0.085	0.053	0.215	0.05	0.86	0.029	0.31	0.80
			outflow	0.076	0.041	0.196	0.049	0.79	0.025	0.25	0.70
		Clay tile	Inflow	0.064	0.048	0.286	0.036	0.53	0.022	0.19	0.60
			outflow	0.057	0.037	0.221	0.033	0.52	0.019	0.16	0.50
		Concrete	Inflow	0.059	0.036	0.201	0.043	0.65	0.032	0.24	0.90
			outflow	0.046	0.028	0.187	0.04	0.61	0.029	0.18	0.50
	60	Asbestos	Inflow	0.053	0.043	0.165	0.042	0.61	0.019	0.25	0.70
			outflow	0.033	0.036	0.152	0.038	0.56	0.015	0.21	0.30
		Clay tile	Inflow	0.032	0.026	0.183	0.032	0.49	0.016	0.11	0.80
			outflow	0.021	0.021	0.172	0.03	0.35	0.011	0.09	0.70
		Concrete	Inflow	0.026	0.016	0.142	0.039	0.38	0.028	0.19	0.90
			outflow	0.019	0.019	0.123	0.035	0.25	0.027	0.16	0.81
600	100	Asbestos	Inflow	0.076	0.026	0.204	0.049	0.81	0.025	0.31	0.60
			outflow	0.056	0.018	0.183	0.045	0.72	0.024	0.28	0.45
		Clay tile	Inflow	0.069	0.020	0.256	0.032	0.54	0.016	0.18	0.50
			outflow	0.042	0.011	0.202	0.028	0.46	0.014	0.14	0.20
		Concrete	Inflow	0.049	0.014	0.195	0.024	0.61	0.03	0.20	0.70
			outflow	0.026	0.007	0.165	0.039	0.56	0.029	0.15	0.62
	60	Asbestos	Inflow	0.046	0.019	0.141	0.04	0.62	0.02	0.21	0.60
			outflow	0.034	0.015	0.134	0.039	0.45	0.018	0.18	0.39
		Clay tile	Inflow	0.031	0.010	0.156	0.035	0.28	0.019	0.10	0.50
			outflow	0.025	0.009	0.149	0.031	0.19	0.018	0.08	0.48
		Concrete	Inflow	0.019	0.007	0.129	0.028	0.39	0.025	0.16	0.70
			outflow	0.01	0.005	0.116	0.026	0.25	0.024	0.13	0.59

IMPROVEMENT OF PURIFICATION SYSTEM FOR ROOF WATER HARVESTING

by

SWATHA,V.S.

(2013 – 18 – 107)

ABSTRACT

Submitted in partial fulfilment of the

requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA

2015

ABSTRACT

The severity of water scarcity and the need of water conservation, appropriate to the situation, are well understood facts and do not require any further elaboration. Knowing the potential of rooftop rainwater harvesting in Kerala state, the government has introduced legistation making rooftop rainwater harvesting mandatory for all newly constructed residential and commercial buildings. However, the roof water harvesting techniques is crippled with the inefficiency of the commonly employed sand and gravel purification system. The major deficiency of the system lies in the difficulty in cleaning of the filter media. Though studies have been initiated with alternative purification methods, it warrants further modification and improvisation. Keeping this in mind, this M.Tech research work has been taken up to find solutions to the purification issues of rooftop rainwater.

The major focus of the work was to develop more efficient micro mesh filter in combination with a first flush system. To evaluate the performance of the filter and first flush, inflow and outflow of the roof water samples were analysed for pH, electrical conductivity, TDS, TSS, metal concentration and microbial parameters. In general, the pH, electrical conductivity and TDS of the roof water samples were within the drinking water standards for the different types of roofs tested. Micromesh purification reduced these quality parameters to further lower levels (10 to 20 percentage). Major TSS load was organic and its concentration was far beyond the permissible limit. Filtration with first flush system could reduce 88 percentage of the organic impurities. Metal and microbial concentrations of the roof water were within the permissible limits, the micromesh filtration could reduce their presence further by about 10 to15 percentage. There is further scope for improving the efficiency of mesh filters by adopting mesh sizes lower than 25 micron for which the discharge of the filter would not be a constraint, as has been revealed by the study.