Development of a filter system for roof water harvesting

By

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(2012 - 18 - 103)

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

2014

DECLARATION

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

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Shijila Erikottil

Dedicated to

My profession

and family

CONTENTS

Chapter No.	Title	Page No.
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
	LIST OF PLATES	x
	SYMBOLS AND ABBREVIATIONS	xi
1	INTRODUCTION	1
2	REVIEW OF LITERATURE	5
3	MATERIALS AND METHODS	30
4	RESULTS AND DISCUSSION	46
5	SUMMARY AND CONCLUSION	64
	REFERENCES	67
	APPENDICES	
	ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
2.1	Quality parameter with different standards	24
4.1	pH of the rooftop water samples	47
4.2	Electrical conductivity of samples in µS/cm	48
4.3	Turbidity of samples in NTU	49
4.4	Suspended solids of given samples in mg/l	49
4.5	Moisture content of moss collected during dry period	54
4.6	Coliforms count in the roof water samples	60
4.7	Filtration rate of different filter systems	61
4.8	Reduction in the impurity concentration	62
4.9	Filtration efficiency of different filter combinations	63

LIST OF FIGURES

Figure No.	Title	Page No.
3.1	Existing upward flow micro mesh filter	32
3.2	Sectioned view of sand filter	32
3.3	Arrangement of mesh and sand filter	33
3.4	Sectioned view of charcoal filter	34
3.5	Arrangement of mesh and charcoal filter	34
4.1	pH of different roof water samples	50
4.2	Electrical conductivity of different roof water samples	50
4.3	Turbidity of different roof water samples	50
4.4	Suspended solids of different roof water samples	50
4.5	pH of the inflow and outflow of the mesh filter	51
4.6	EC of the inflow and outflow of the mesh filter	52
4.7	Turbidity of the inflow and outflow of the mesh	52
4.8	Suspended solids in the inflow and outflow water	53
4.9	pH of inflow and outflow of synthetic roof water	55
4.10	EC of inflow and outflow of synthetic roof water	56
4.11	Turbidity of inflow and outflow of synthetic roof water	57
4.12	Suspended solids of synthetic roof water	58
4.13	BOD of inflow and outflow of filters	59

LIST OF PLATES

Plate No.	Title	Page No.
3.1	Experimental setup of roof water purification	36
3.2	Synthetic roof water	37
3.3	Systronics water quality analyzer	39
3.4	pH electrode	40
3.5	Conductivity cell	41
3.6	Gravimetric experimental setup	42

SYMBOLS AND ABBREVIATIONS

'	-	Inch
µS/cm	-	microSiemens/cm
ADWG	-	Australian Drinking Water Guideline
BIS	-	Bureau of Indian Standards
BOD	-	Bio-chemical Oxygen Demand
BUET	-	Bangladesh University of Engineering and Technology
cm	-	Centimeter
CGWB	-	Central Ground Water Board
COD	-	Chemical Oxygen Demand
CPCRI	-	Central Plantation Crops Research Institute
DRRWH	-	Domestic Rooftop Rain Water Harvesting
DRWH	-	Domestic Rooftop Water Harvesting
dS/m	-	deciSiemens/m
EC		Electrical Conductivity
EPA	-	Environmental Protection Agency
et al.	-	and others
FAD	-	Filtration Adsorption Disinfection

Fig.	-	Figure
GBPUAT	-	Govind Ballabh Pant University of Agriculture & Technology
GI	-	Galvanized Iron
GIS	-	Geographical Information System
Gm	-	Gram
GWAMP	-	Geographic Water Management Potential
h	-	Hour(s)
i.e	-	that is
KAU	-	Kerala Agricultural University
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
KSCST	-	Karnataka State Council for Science and Technology
l	-	Litre
m	-	Meters
m^3	-	Cubic meters
mg/l	-	Milligram per litre
ml	-	Milliliter
mm	-	Millimeters
min	-	Minute

MTA	-	Male Thread Adapter
NIT	-	National Institute for Technology
No.	-	Number
NRDC	-	Natural Resources Defense Council
NTU	-	Nephelometric Turbidity Units
PVC	-	Poly Vinyl Chloride
PWS	-	Public Water System
RCC	-	Reinforced Cement Concrete
RRWH	-	Rooftop Rain Water Harvesting
RWHS	-	Rain Water Harvesting System
RWHP	-	Roof Top Water Harvesting Potential
TC	-	Terracotta
TCEQ	-	Texas Commission on Environmental Quality
UK	-	United Kingdom
UNDP	-	United Nations Development Programme
UNICEF	-	United Nations International Children's Emergency Fund
US EPA	-	United States Environmental Protection Agency
viz.	-	namely
WHO	-	World Health Organization

Introduction

CHAPTER 1

INTRODUCTION

Water is the most vital resource on the earth required by all life forms, from micro organisms to humans. However, its availability is on the decline in all parts of the world due to reasons such as climatic change, population growth and change in life style. Increase in water demand has led to the over exploitation of ground water and consequent drying up of shallow wells and tube wells. The nation India and the state Kerala is not different from the above said scenarios. Urban and rural areas of India experiences water scarcity of different orders. Urban areas are equipped with centralized water supply system where as rural areas have only decentralized water supply sources. In both the cases failure of supply system due to non availability of water is very common.

The state of Kerala has paradoxical extremes in the case of water availability. In the monsoon season, there is water surplus due to very high rainfall. Water storage in the unconfined aquifer is very marginal due to its shallow depth. Unconfined aquifer is underlined by hard rocks with very little fractures and fissures to facilitate storage and movement of water. As a result, the overall ground water potential of the state is very low. This will lead to water shortage immediately after the recession of the monsoon. Practical solutions to tide over the situation are very imminent and it warrants serious thought processes. It is imperative to take adequate measures to meet the drinking water and other domestic needs of the people in the country as the first priority and then irrigation and other needs.

Rain is the ultimate source of fresh water. And it continues to be the major source of consumption of humans and animals. It is valued for its purity and softness. It has nearly neutral pH, and is free from disinfection byproducts, salts, minerals, and other natural and man-made contaminants. Hence, rainwater harvesting can be an effective and low-cost solution to tide over water scarcity especially the domestic one. Much of this rainwater could be stored and reused, offsetting the need for processed pipe water being supplied by incurring high cost. The rainwater harvesting is a technique used for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple methods such as pots and tanks as well as more complex techniques such as underground check dams. It can be recharged into the ground to improve ground water storage. Water that is not extracted from ground during rainy days is the water saved.

Rainwater harvesting can make important contribution in resolving water shortages of the present and the future. The technology is flexible and adaptable to a very wide variety of conditions and situations. It is practiced in the richest and the poorest societies, as well as in the wettest and the driest regions on the earth. Rainwater harvesting for domestic use usually involves collecting water from cleaner surfaces, such as roofs. In such cases, roof is the most direct contamination path in rainwater harvesting. It is well understood that there are a lot of filthy and offensive things on a roof surface that must be removed from the water to make it usable and safe. In areas with significant seasonal variations in the annual rainfall pattern, the matching of water supply and water demand would be difficult. In such places also roof water harvesting would come very handy.

In terms of economic and human welfare, it has a crucial role to play. Rainwater in many cases is the easiest to access, most reliable, and comparatively less polluted source. It can be collected and controlled by the individual household or community as it is not open to abuse by other users. In addition to domestic use, water from rooftop can be used for utility purposes such as irrigating decorative plants or washing out gutters; and these can usually be carried out safely without extensive purification. On the other hand, if the water is to be used for drinking, it must undergo adequate filtering and purification. Several studies have shown that water from well maintained and covered rooftops generally meets drinking water quality standards. It enables households as well as community buildings, schools and clinics to manage their own water supply for drinking, other domestic use, and income generating activities. Usually these systems are designed to supply the drinking and cooking needs of the family at the doorstep. Contaminants in roof water may include algae, air pollution, bird excrement, leaves, sand, and dust. Water purification generally means freeing water from any kind of impurity it contains, such as organic matter, mineral matter or micro organisms. By properly designing and operating rainwater harvesting system, it can minimize the presence of a variety of chemical contaminants that include organic chemicals, such as volatile and synthetic organics, and inorganic chemicals, such as minerals and metals.

Domestic rainwater harvesting is one of the important categories of rainwater harvesting where water is collected from rooftops, courtyards and similar compacted or treated surfaces, stored in underground tanks or aboveground tanks and used for domestic purposes. Rainwater falling on the roof is generally very pure and clean. However, many substances like leaves, bird droppings, dust etc. get mixed up with this pure water on the roof. Most importantly, the first few millimeters of dirty rainfall runoff should be diverted away from the tank to avoid contamination. Therefore it is desirable that rainwater is only harvested after the roof has been washed off by the initial rainfall. The storage tank should also be cleaned periodically, as some of the particles can settle in the storage tank, especially when the stored water is cycled rarely. The storage tank should be well covered to prevent insects using it as a breeding place. These contaminants need to be adequately filtered before the rainwater is stored. A wide range of apparatus are used in the removal of fine suspended particles from rainwater, including filtration using membrane, sand, granular activated carbon, and expanded clay and gravel. Despite the growing variety of filters for rainwater purification available in the market worldwide, there are limitations in this technology that need to be addressed.

Water purification has several methods and processes. The kind of treatment and it's extend depends, to a great extent, on whether it will be used for potable purposes or for non potable purposes. Obviously, rainwater that is intended for potable purposes must receive higher levels of treatment than rainwater that is intended for small scale irrigation and other purposes. The quality of roof water can be improved considerably if debris is kept out of the system. To accomplish this, filters and separators can be added to a rainwater harvesting system at the inlet, outlet or both. Filters simply catch the debris and allow clean water to flow through. Whatever design is chosen for the filter, there are several criteria that should be met for a good design. The filter should be easy to clean, it should not get blocked easily, it should not provide an entrance for additional contamination of the stored rainwater.

Commonly available filter system for rain water harvesting consists of sand and gravel media placed in a container, usually made of ferrocement, and is fitted to the top of the storage tank. One of the major limitations of this filter system is its difficulty in cleaning. Because of no periodic cleaning, the filter media will go clogged and the system becomes dysfunctional in a very short span of life. Hence, an alternative to the existing filter system for roof water harvesting is an immediate necessity. In this context, this study has been proposed to design and develop a more efficient and hassle free filter system for domestic roof water harvesting with the given below specific objectives.

- To evaluate the performance of a mesh filter for roof water harvesting
- To modify the design of the existing filter system
- To evaluate the filtration efficiency of the modified filter system

Review of literature

CHAPTER 2

REVIEW OF LITERATURE

2.1 Rain water harvesting

As the global population advanced the 7 billion mark in 2011, the earth's already limited resources are placed under increasing demand. Water is a resource of critical importance, and although significant strides have been made towards improving access to water, challenges brought about by climate change continue to compound water scarcity challenges. According to UNICEF and WHO, over 780 million people remain in need of improved sources of drinking water, with 2.5 billion lacking improved sanitation. A variety of environment friendly and sustainable techniques have been developed in response to challenges associated with the provision of clean water supplies. Rain Water Harvesting (RWH) is one such alternative water supply source (UNICEF, 2004).

Rainwater harvesting involves the collection and storage of rainwater, which is used for domestic, agricultural, industrial and environmental purposes. It has globally been practiced in various forms for centuries, as an alternative to unsafe or limited underground water resources (Environment Agency, 2010). Rainwater harvesting is economically feasible only when the magnitude and frequency of rainfall and size of the catchment surface can generate sufficient water for the intended purpose. Today, RWH is increasingly recognized as a relatively low-cost intervention which can be employed to improve access to clean water, and which has the potential to better people's livelihoods. The rain water harvesting is mainly done for the following purposes.

1. For direct use.

2. For augmenting groundwater storage.

Rajan (2001) conducted a study on rain water harvesting in Indo Gangetic plains of Dihra village in Bihar. Here, the traditional Pyne and Anars have been irrigated using rain water at times, when the zonal canal failed to meet the purpose.

Rana (2002) has reported from the study conducted at Khulna district in Bangladesh that if RWHS supply water year round to meet the needs of a nuclear family, the demand could not exceed 1000 liters per month. The effective management of water resource demands a holistic approach of linking social and economic development with protection of natural ecosystem.

A rainwater harvesting system was developed by Visalakshi *et al.* (2006) at KAU, Thrissur, Kerala as a safeguard against water crisis of the campus. The 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 was utilized for ground water recharge by providing gravel packed percolation pits of size 2 m diameter, with 2 m depth. Another pond of 1,00,000 l capacity lined with 300 micron geo-membrane and top covered by 75 percent shade net for minimising evaporation losses and preventing entry of debris was also constructed for meeting the irrigation needs of the farm.

Manzurul *et al.* (2007) reported a feasibility study of rainwater harvesting techniques in Bangladesh. This research explored the possibility of harvesting rainwater in rural communities of Bangladesh as well as densely populated city like Dhaka, using simple and low cost technology. In this connection, rainwater has been experimentally harvested at Bangladesh University of Engineering and Technology (BUET) in the monsoon using a small catchment area (15’ x 15’) made of water proof cloth and a ferro-cement storage tank having capacity of 3200 l for 5 member family and the rainwater was stored for 4 months. Additionally, the research also looked at the quality aspect of the stored rainwater including color, total solids, total dissolved solids, lead, turbidity, hardness, acidity, pH, nitrate, fluoride, total coliform, fecal coliform, COD, and BOD. Initial test results indicated that the stored rainwater had a slightly higher pH value (8.1 to 8.3) and presence of coliform bacteria (when water is stored for more than three months) was also detected.

The opportunities in rainwater harvesting have been reported by Helmreich and Horn (2008). Depending on precipitation magnitude rainwater constitutes a potential source of drinking water. They stated that the proper management of RWH could reduce water and food crisis in some of the regions of developing countries. Rainwater harvesting (RWH) is a technology where surface runoff is effectively collected during yielding rain periods. In order to support such technologies, RWH systems should be based on local skills, materials and equipment. Harvested rainwater can then be used for rainfed agriculture or water supply for households. Unfortunately, rainwater might be polluted by bacteria and hazardous chemicals necessitating treatment before use. The study reported that slow sand filtration and solar technology are the new methods to reduce the pollution. Membrane technology would also be a potential disinfection technique for a safe drinking water supply.

The impact of rooftop rainwater harvesting for groundwater recharge under the Punjab Agricultural University was reported by Agarwal *et al*. (2010). As part of the study, a rooftop rainwater harvesting structure was constructed and the design of filtration unit for ground water recharge evaluated for four years. The other structure constructed at the university library recorded an average of 2.01 million litres groundwater recharge per annum. The study reports that there was a need to adopt this technique at mass level to get significant results.

Constantain *et al.* (2010) has developed a system of rainwater collection, storage and pumping. The technical system of rainwater, 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 Science 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.

Fergal *et al*. (2010) conducted a study on rainwater harvesting and greywater treatment systems for domestic application in Ireland. The use of domestic rainwater harvesting and greywater treatment systems has the potential to supply nearly 94% of domestic water in Irish households. The results revealed that the utilization of these systems can help Irish householders achieve significant water savings and avoid the domestic water bills that are due to be reintroduced. It also helps to relieve the pressure of the centralized water supply to meet the increasing water demand in Ireland and eliminates issues such as high leakage during delivery and large treatment costs for domestic utilization.

The environment agency at Bristol (2010) published an information guide for harvesting of rainwater for domestic uses. This document provided the information on rainwater harvesting systems in the UK. It covered the supply of non-potable water for domestic uses such as flushing the toilet, watering the garden and washing clothes by a washing machine using the harvested rain water.

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 reservoirs. Harvested rain water can be stored in sub-surface ground water reservoir by adopting artificial recharge techniques to meet the household needs through storage in tanks. The roof water harvesting is one of the extensively used methods of rainwater harvesting. The main objective of rooftop rain water harvesting is to make water available for future use. Capturing and storing rain water for use is particularly important in dry land, hilly, urban and coastal areas. Rainwater harvesting usually involves collecting water from cleaner surfaces, such as roofs. Most of the rainwater collection systems are cost effective and easy to maintain by the average house owner and are easier to install than wells or surface ponds (Thomas and Martinson, 2007).

The components of the system are the roof catchments, collection device, the conveyance system, first flush valve, filter unit, storage tank and overflow pipe to recharge pit. As the rooftop is the main catchment, the amount 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 collection efficiency or the coefficient of runoff accounts for the rain water falling over an area that cannot be effectively harvested. The runoff coefficients vary from 0.7 to 0.9 with the type of roofing materials.

Tamim *et al*. (1998) conducted a study to evaluate the rooftop rainfall collection using cistern storage systems in southwest Virginia. The main objective of this study was to gather information about cistern use, properties, and management in the isolated communities of southwest Virginia. The survey indicated that more than 30 percent of the households in the surveyed areas depend on cisterns for their drinking water needs, and that 20 percent of the cisterns run dry at least once a month.

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

Dinesh (2004) has reported that hydrological opportunities for RWHS are very poor in urban and rural areas and it may be economically viable as a supplementary source to already existing public water supply schemes. The study analyzed the scope, physical feasibility, and economic viability of roof water harvesting systems across different physical and socioeconomic classes of the society. The article states that roof water harvesting systems (RWHS) are not an alternative to public systems in urban and rural areas receiving low rainfall.

Dwivedi and Bhadauria (2004) have conducted a study based on the analysis of survey record of around 50 houses having different sizes of rooftop of urban area of Dhule city. The estimation of the appropriate size of the water tanks and their costs required to fulfill the annual drinking water demands through Domestic Rooftop Water Harvesting (DRWH) from rooftops of different areas were done. As a part of their work the DRWH systems for all houses was designed considering the existing rain water outlets and cost estimation for each individual house was also done. A mathematical equation expressing the relationship between the required size of water tank and different rooftop areas was developed as given below.

$$C_D = 3265 \times \ln(A) - 6462$$

Where; C_D = Cost of DRWH System in Rupees and A = Rooftop Area in m^2.

Water Environment and Sanitation Section, UNICEF, New Delhi, India (2004) carried out a study on evaluation of the rooftop rainwater harvesting in the states of Kerala, Maharashtra and Uttar Pradesh. The study revealed that the implementation of the project in Uttar Pradesh and Maharashtra was partly responsible for the failure of the RRH projects over there. One of the possible reasons for this was the involvement of multiple agencies resulting in uncoordinated execution, lack of accountability and increase in overheads.

Evans *et al.* (2006) reported the effect of weather on the microbial composition of roof harvested rainwater. This study involved analyses of direct roof run off 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. The results indicated that the aerobic microorganisms represented a significant contribution to the bacterial load of roof water at this site, and that the overall contamination was influenced by wind velocities.

Karnataka State Council for Science and Technology (KSCST) took up a research work on rainwater harvesting from rooftops under the leadership of Shivakumar (2006). They constructed a rain water harvesting system and studied roof area calculation for different roofs, storage and filtering systems used for this purpose.

Thomas and Martinson (2007) have proposed a roof water harvesting handbook for practitioners. This was meant to serve as a source of material for rainwater harvesting associations preparing national design guidelines in local languages. Finally, it could be used by individual householders to design single roof water harvesting systems.

In 2007 the Texas Commission on Environmental Quality (TCEQ) has presented a paper on rainwater harvesting guidance for public water systems. This was a guide for public water systems (PWS) that collect and treat rainwater and distribute it as potable water. The PWS is defined as any system that serves at least 25 people per day for at least 60 days in each year or that serves at least 15 service connections.

For water supply, a low impact a roof water harvesting system was developed by Brock and Kate (2008) at Brazil. They used the term “low-impact” to describe this system because it models the design concepts of Low Impact Development which is a storm water management approach with a basic principle that is modeled after nature manage rainfall at the source using uniformly distributed decentralized micro-scale controls and mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. The result was a hydrologically functional landscape that generates less surface runoff, less pollution, less erosion, and less overall damage to lakes, streams, and coastal waters.

Manoj and Mathew (2008) published a case study on rejuvenation of water bodies by adopting rainwater harvesting and groundwater recharging practices in catchment area under the Central Plantation Crops Research Institute (CPCRI), Kasargod, Kerala (India). The studies suggested that these technologies are sustainable, locally adoptable, cost-effective and affordable to the farmers. This study also revealed that the rejuvenation of the traditional water harvesting structures in the district and the implementation of community water management schemes with maximum people's participation are the suitable options to mitigate all the ill effects of drought and soil erosion prevalent in the area (Manoj and Mathew, 2008).

Fayez *et al.* (2009) conducted a study on roof rainwater harvesting systems for household water supply in Jordan. The objectives of this paper was to (1) evaluate the potential for potable water savings by using rainwater in residential sectors of the 12 Jordanian governorates; and (2) provide some suggestions and recommendations regarding the improvement of both quality and quantity of harvested rainwater. Results showed that a maximum of 15.5 Mm^3/year of rainwater can be collected from roofs of residential buildings provided that all surfaces are used and all rain falling on the surfaces is collected. That was equivalent to 6% of the total domestic water supply of the year 2005.

Beckman *et al.* (2011) of National Research Development Corporation (NRDC) reported a research work on capturing rainwater from rooftops at different places of United States. The analysis evaluated the available daily rainfall and conservatively estimated non-potable water demands to determine reasonable projections for the amount of potable water demand that could be replaced by using rainwater for eight selected U.S. cities. To determine the available amount of rooftop rainwater that could be captured in each of the cities, GIS data were used to identify the total land area of residential and non-residential roofs.

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 is analyzed to determine the probability of occurrence. The study revealed 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 are proposed for college buildings.

The planning and cost estimation of roof rainwater harvesting structure was reported by Reena and Sherring (2012). The study was conducted at Allahabad Agricultural Institute, a Deemed University, to find the possibility of rainwater harvesting from the roof of Biotechnology Building. For this study, the last ten year daily rainfall data was analysed and future rainfall was predicted with 75 percent probability limit. The estimated rainfall at 75 percent probability limit of rainfall was 547.8 mm with recurrence interval of 1.33 years. The four month rainfall of June to September was considered to estimate the runoff from the roof top. The design dimensions of the reservoir was estimated as 12 m x 10 m x 3.05 m with the storage capacity of 366 m^3 and the cost of storage of harvested water was estimated as 0.1 rupees per litre.

Ying Lim *et al*. (2013) studied the reevaluation of health risk benchmark for sustainable water practice through risk analysis of rooftop harvested rain water (HRW). In their study, they challenged the current benchmark of risk by quantifying the potential microbial load associated with consumption of roof harvested rain water.

Results showed that the 95th percentile values of infection risk per intake event of home produced roof water are one to three orders of magnitude (10^{-7} to 10^{-5}) lower than US EPA risk benchmark (10^{-4}). They further discussed the desirability of HRW for irrigating home produced food crops. Further, the study proposed the need of an updated approach to assess appropriateness of sustainable water practice for making guidelines and policies.

2.3 Components of RRWH system

A rainwater harvesting system comprises components for various stages such as transporting rainwater through pipes or drains, filtration, and storage in tanks for reuse or recharge. Common components of a rainwater harvesting system reported by some important studies (Chris Brown *et al*., 2005; Luke, 2005; Doyle and Peter, 2010; John, 2011) are presented here.

2.3.1 Catchments:

The catchment of a water harvesting system is the surface which directly receives the rainfall and provides water to the system. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground. A roof made of reinforced cement concrete (RCC), galvanised iron or corrugated sheets can also be used for water harvesting. Since rainwater is pure as it falls from the sky, it is necessary that the roof be kept clean for water to remain pure when it is collected. When cleaning the roof with water the first rain separator must be kept open so as not to allow the dirt to enter the filter and the tank.

2.3.2 Gutters:

These are the channels provided all around the edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular and could be made using:

- Locally available material such as plain galvanised iron sheet (1.15 to 1.25 mm), folded to required shapes.
- Semi-circular gutters of poly vinyl chloride (PVC) pies
- Bamboo or betel trunks cut vertically into two halves.

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 Conduits:

Conduits are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Conduits can be of any material like PVC or galvanized iron (GI) which are commonly available.

2.3.4 First-flushing:

A first flush device is a valve that ensures that runoff from the first spell of rain is flushed out and does not enter the system. This needs to be done since the first spell of rain carries a relatively larger amount of pollutants from the air and catchment surface. It will also help in cleaning of silt and other material deposited on roof during dry seasons. Provisions of first rain separator should be made at outlet of each drainpipe. After screening the gutters, a first flush device is the next line of defense for keeping the system and water clean. This is especially important if the water is used inside the house or in situations where children or those with weakened immune systems may come in contact with the water.

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. For 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 would be reduced by less than 2% with diversion of the recommended first flush, while the turbidity would be decreased by 50%. Diversion of the first flush was found to reduce reliability by at most 8%. Analysis of three existing RWH systems indicated that a recommended 1 mm first-flush diversion would reduce the number of days the system meets demand by no more than 7 days per year.

For the evaluation of first flush, Kus *et al.* (2010) conducted a study on the evaluation of 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 a rainwater tank. 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.

2.3.5 Filter system:

The filter is used to remove suspended pollutants from rainwater collected over the roof. 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, but basic function is to purify water

(i) Charcoal water filter

A simple 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 (Manohar, 2010).

(ii) Sand filter

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. In a simple sand filter that can be constructed domestically, the top layer comprises coarse sand followed by a 5-10 mm effective size gravel layer followed by another layer of gravel and boulder (John, 2011).

(iii) Mesh filter

A micro-mesh screen can filter debris in 80-100 micron size which is beneficial for potable or indoor fixture systems which require superior filtration. Filters are measured in microns. For comparison, it is given that 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. The rainwater collected from the roof and stored in tanks has poor quality level so that it is suitable only for showers, washing machines, gardening and other domestic uses.

An iron hydroxide coated sand medium for removing bacteria and heavy metals from roof harvested rainwater was developed by Ahammed and Meera (2006) at Cochin, Kerala. The study showed the potential of iron hydroxide coated sand as a sorptive filter medium for use in simple home water purification devices for treatment of roof harvested rainwater.

Kiran *et al*. (2009) conducted a study on the feasibility of RRWH in KCAET Tavanur, Malappuram. The filter was able to remove about 87% of the impurities. The study concluded that the system can be strongly recommended for households facing problems of water scarcity and also quality.

A rooftop rainwater harvesting structure was constructed and the design of filter unit for ground water recharge evaluated for four years in Punjab Agricultural University, Ludhiana (Agarwal *et al.,* 2010). For this study, currently 20 structures have been established at different places in Punjab under the technical guidance of the university. In the year 2007, eleven structures were evaluated and found that they contributed about 2.01 million litres of rainwater as groundwater recharge. The study revealed that there was a need to adopt this technique at mass level to get significant results.

Harishankar *et al*. (2010) developed an improved design of RRWH at KCAET Tavanur, Malappuram, Kerala. 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 $m^3/min/m^2$ and 90% respectively. The study concluded that the improved design was more efficient.

A research work on water purification using magnetic assistance was reported by Ritu and Mika (2010). With the increase in demand, 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 adopted from ore mining industries to anti-scale treatment of pipe lines to seeding magnetic flocculent. This article explained a series of information on this water purification technique and explains different aspects of magnetism and magnetic materials for water purification.

John (2011) presented a paper on the options and necessities of rain water filtration. They explained on different filter systems used for rainwater harvesting and quality of the filtered water.

In 2011 roof water harvesting structure and Slow Sand Filters (SSF) were developed by Khadse *et al*. 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 is 9 m^3/d. It is worth mentioning that this is a water treatment technology without 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 slow sand filtration for rainwater treatment in airports followed by chlorination was developed by Ronan *et al*. (2012) and they calculated efficiency and 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 current water supply company.

Russells *et al.* (2012) reported 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 stormwater management technology and redefines it to help meet the growing water supply demand in the city of Warrnambool.

Naddeo *et al*. (2013) reported a study on enhanced drinking water supply through harvested rainwater treatment. They focused on an innovative decentralized system that can be used to collect and treat rainwater for potable use (drinking and cooking purposes) of a single household, or a small community. Analytical measurements were made at the Environmental Engineering Laboratory of the University of Salerno, Fisciano (SA), Italy. The study revealed that the Filtration Adsorption Disinfection (FAD) unit is able to produce pure water in terms of microbiological quality; it provides an absolute barrier for pathogens and several major contaminants, also reducing turbidity. The cost of FAD units is relatively low, which makes the system accessible to small communities and households located in developing, water stressed countries.

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.

A self-cleaning filtration system for rainwater harvesting was developed by Silva *et al*. (2013) at Brazil. The objective of this work was to develop and test a novel concept for the filtration of particles in raw rainwater with no energy usage, self-cleaning mechanism, and simple installation and operation for buildings. The concept was tested by building a prototype, in which the treatment efficiency for particle removal as well as the backwash efficiency was assessed for three different filter media. A polypropylene woven filter fabric with 75 µm pore size and 1.07 mm thickness was used as a prototype system that was operated with 68 % of treatment efficiency and 100 % backwash efficiency. 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.

2.3.6 Storage system

The rainwater storage tank collects all the filtered rainwater and keeps it for future use. The storage tank is made above the ground and on a platform. It can also be an underground sump in some cases. The tank is invariably painted white on the outside. This is done to keep the water inside cool and prevent the growth of bacteria. The tank also will be sealed from the top either with "Cuddapah" slabs or concrete slabs or any local stone. It must be ensured that the top cover is permanent and always fully covered. This will prevent the growth of algae or bacteria in the tank. In no case should it be opened. If there are small cracks in the joints they should be sealed with cement mortar immediately. Mosquitoes and dust should never be allowed in to the stored rainwater tank. The tank should also be completely water tight. If there is any leak in the tank or even dampness, the problem should be addressed immediately with the help of a trained engineer (Texas Commission on Environmental Quality, 2007).

Hune and Paul (2002) developed low-cost methods of rainwater storage. The main aim of the investigation, as reported, was to find low-cost, appropriate and sustainable methods for rainwater storage. For this purpose, trials were carried out in Ethiopia and Kenya. Five different methods of tanks construction were tested in Ethiopia and six different methods in Kenya. The trials in the two countries were not identical because of the different materials that were available and the different ideas of what might be workable in the local situation.

A rain water harvesting project was carried out by Khandagale *et al.* (2003) at VIKAS Complex, B wing, Thane. For their study they have collected 5000 litres of rainfall in the morning and evening from five buildings. So the five building was supplied 50000 l/day. The results concluded that the rainwater was conserved and utilized using the rainwater harvesting technology and it can be an effective tool of replenishing ground water resources.

Chao and Yao *et al.* (2004) conducted a study on optimum storage volume of rooftop rain water harvesting systems for domestic use at Taiwan. The field experiment was conducted to determine the runoff coefficient more precisely for various types of roofs. A simulation model including production theory was developed and employed to estimate the most cost effective combination of the roof area and the storage capacity that best supplies a specific volume of water. Consequently, the expansion path of optimum solutions for different volumetric reliability of water supply can be determined.

A method was developed to find out size of storage reservoir by Janette Worm *et al.* (2006). They revealed that this was the simplest method to calculate the storage requirement based on the required water volume (consumption rates) and occupancy of the building. This approach was only relevant in areas with a distinct dry season. The tank was designed to meet the necessary water demand throughout the dry season. To obtain required storage volume the following equation has been suggested.

$$\text{Demand} = \text{Water Use} \times \text{Household Members} \times 365 \text{ days}$$

This equation provides the water demand in litres per year. Dividing by 12 months will give the required water demand in litres/month. The required monthly water demand multiplied by the dry period will give the required storage capacity

$$\text{Required storage capacity} = \text{demand} \times \text{dry period}$$

A remote sensing and GIS based water harvest and storage location assessment model was developed by Weerasinghe *et al*. (2011). This study described a globally applicable method to determine the local suitability to implement water supply management strategies within the context of a river catchment. They applied this method, and developed a spatial analysis model named Geographic Water Management Potential (GWAMP). Based on the results from testing and validation of the GWAMP they point out that the GWAMP can be used to identify potential sites for rain water harvesting and storage technologies in a given catchment.

2.4 Harvested rainwater quality effects on roofing material

Good quality rainwater is likely to be harvested and stored if the Domestic Roof Water Harvesting system (DRWH) is designed well, and is operated and maintained efficiently. The quality of domestic rooftop harvested rainwater is mainly dependent on the local air quality and roof cleanliness. The roof is the most direct contamination path in rainwater harvesting. Particles, micro-organisms, heavy metals and organic substances, accumulated on the roofs, can greatly affect the harvested rainwater quality. It is very important to clean the roof regularly to remove dust and debris (Rainwater Harvesting Implementation Network (RAIN), 2008).

Most importantly, the first few millimeters of dirty rainfall runoff should be diverted away from the tank to avoid contamination. Therefore, the rainwater is only harvested after the roof has been washed off. The storage tank should also be cleaned periodically, as some of the particles can settle in the storage tank, especially when the stored water is cycled rarely. The storage tank should also be well covered to prevent insects using it as a breeding place. Bacteria, viruses and protozoa may originate from faecal pollution by birds and mammals on the roof and storage tank. The presence of bacteria and pathogens suggest that the harvested rainwater is generally not suitable for drinking. These bacteria and pathogens will gradually die off during the first several days of storage if the storage tank can avoid both light and organic matter (TCEQ, 2007). Nowadays different methods have been used for the bacterial treatment. The permissible limit of various quality parameters based on different standards is given below (Table 2.1).

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	--	--
Cloride (mg/l)	250	250	250
Lead (mg/l)	0.01	0.01	Zero
Total hardness (mg/l)	100	600	--
Total coliforms (no. /100ml)	0	0	0

Yaziz *et al*. (1989) reported the variations in rainwater quality from roof catchments near the University of Agriculture campus in Serdang, Selangnr. The quality of rainwater from a tile and a galvanized-iron type roof catchments were analysed over a period of 5 months. Examination of staggered 1 litre samples collected during a rainfall event showed that the concentrations of various pollutants were high in the first litre but decreased in subsequent samples with few exceptions. Faecal coliform and total coliform counts ranged from 8-13 (tile roof) and 4-8 (iron roof) to 41-75 (tile roof) and 25-63 (iron roof) colonies per 100 ml respectively. They concluded that the rainfall intensity and the number of dry days preceding a rainfall event significantly affects the quality of run-off water from the catchment systems.

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 have 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.

An estimate of deaths from water-related diseases during 2000-2020 was published by Peter (2002). This paper examined the different scenarios of activities in the international water arena and provides three estimates of the overall water related mortality likely to occur over the next two decades. The study revealed that the problem is one of the most serious public health crisis facing us, and deserves far more attention and resources than it has received so far.

Bineesh *et al*. (2004) conducted a research study on salient features of ground water resource and quality of drinking water of 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.

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.

The water quality of rainwater harvesting systems was evaluated and published by Luke (2005). The purpose of this report was to outline best-practice techniques for rainwater collection systems in order to produce good water quality.

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 has been 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 analyses 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.

Ramachandra and Malvikaa (2007) reported the ecological assessment of lentic water bodies of Bangalore. The study carried out on two water bodies, namely, the Chamarajasagar reservoir and the Madiwala Lake. The waterbodies were selected on the basis of their current use and locations. The physic chemical analyses included temperature, transparency, pH, electrical conductivity, dissolved oxygen, alkalinity, total hardness, calcium hardness, magnesium hardness, nitrates, phosphates, sodium, potassium and COD measurements of the given water body. The study indicated that Chamarajasagar reservoir was fairly unpolluted, except for the pH values, which indicate greater alkalinity. This may be attributed to the natural causes and the agricultural runoff from the catchment and the Madiwala lake was greatly influenced by the inflow of sewage that contributes significantly to the dissolved solids of the lake water, total hardness, alkalinity and a low dissolved oxygen level.

The Rainwater Harvesting Implementation Network (RAIN) at Netherland (2008) published a guideline for rainwater quality. This document will address RAIN guidelines towards water quality and will give practical guidelines to improve and maintain an acceptable water quality of harvested rainwater for drinking purpose. It described criteria for water quality of harvested rainwater, placed within the socio-economic and geographical context of RAIN target countries.

The quality assessment of harvested rainwater for domestic uses was conducted by Jamal *et al.* (2009) at northern region of Jordan. For this study, the rainwater collection for domestic use was practiced on regular basis. Ninety samples of harvested rain water from various storage tanks within the four governorates (Zarka, Irbid, Ajlun and Jerash) were collected and analyzed for different quality parameters (pH, alkalinity, Hardness, Turbidity, TDS, COD, NO_3, NH_4, PO_4, Pb, Fe, Cr and biological contaminations). The results of the analysis were compared with valid quality guidelines to evaluate its suitability for domestic uses**.** The resulted data indicate that water quality in these tanks and cisterns varies depending on location, on catchment area, and on the availability of public sanitary systems. The study indicated that the collected water is heavily contaminated with microbes so that it becomes unsuitable for direct drinking purpose. Thus, this water might be used for irrigation purposes.

Wilson (2010) conducted a study on water quality notes on water clarity (turbidity, suspended solids, and color) at University of Florida. The objectives of this document were to provide: 1) an overview of water clarity and how it is influenced by the presence of turbidity, suspended solids, and color; 2) an understanding of the importance of clarity from an ecological perspective; 3) a summary of methods for measuring each parameter; 4) the current state regulations for each in public waters of Florida; and 5) management opportunities to protect and improve water clarity. The study reports that visibility or clarity decreases as the turbidity increases in a given water body. The reduction in clarity was due to scattering of sunlight by suspended particles in the solution.

The quality of harvested rainwater was reported by Ward *et al* (2010). The physicochemical and microbiological quality of water from rainwater harvesting (RWH) system in a UK based office building was tested. 7 microbiological and 34 physiochemical parameters were analysed during an 8 month period. Physiochemically, quality of harvested rainwater posed little health risk; most parameters showed concentrations below widely accepted levels for drinking water.

Kondal *et al*. (2011) made an analytical study on the microorganisms present in rain water of different areas. For this study, the rainwater samples were collected from four different environmental conditions such as forest area, rural area with less and high pollution and industrial area. The quality of this work mainly was on analysis of microbial growth, biological oxygen demand, chemical oxygen demand, temperature, pH, chlorides, carbonates, bicarbonates, sulphates, turbidity and hardness of rain water. The results revealed that the conductivity of rain water shows low values because of the lack of cations and anions. The pH of the rainwater was found to be nearly 5.56. The COD and BOD results showed a significant difference in their values with rainwater of forest area and industrial area.

Mendez *et al*. (2011) conducted a study on the effect of roofing material on the quality of harvested rainwater. For this study, they examined the effect of conventional roofing materials (i.e., asphalt fiberglass shingle, Galvalume, metal, and concrete tile) and alternative roofing materials (i.e., cool and green) on the quality of harvested rainwater. Results from pilot-scale and full-scale roofs demonstrated that rainwater harvested from any of these roofing materials would require treatment if the consumer wanted to meet United State's EPA primary and secondary drinking water standards or non-potable water reuse guidelines when a minimum, first-flush diversion, filtration, and disinfection are provided. This study showed that rainwater harvested from metal roofs tends to have lower concentrations of fecal indicator bacteria as compared to other roofing materials.

Young *et al*. (2012) reported a comparative study on quality of roof-harvested rainwater from different roofing materials. The objective of the study 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 [*Gi-Wa*] and galvanized steel) were installed in a field. 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 (e.g., pH (5.8-8.5), TSS <500 mg/L, NO_3^- <10 mg/L, SO_4^{2-} <200 mg/L, Al <0.2 mg/L, Cu <1 mg/L, Fe <0.3 mg/L, Pb <0.05 mg/L, Zn <1 mg/L, and *E. coli* (*No detection*)). 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 the roof water.

An augmentation of groundwater recharge and water quality improvement by water harvesting structures in the semi-arid Deccan was conducted by Adhikari *et al*. (2013). The effect of water harvesting structures on groundwater recharge and water quality was evaluated in a watershed situated in a semi-arid region in Andhra Pradesh, India. Water quality analysis revealed that except pH, all other water quality parameters like electrical conductivity, sodium adsorption ratio, residual sodium carbonate, total hardness, nitrate and fluoride content reached desirable limits in close vicinity (< 100 m) to the water harvesting structures.

Materials and methods

CHAPTER 3

MATERIALS AND METHODS

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

3.1 Study Area

Study has been conducted on the existing micro mesh filter and the newly developed sand and charcoal filter 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 75% of the annual rainfall is received through South West monsoon (June to September) and the balance 25 % 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 0-5 %. Climate is humid tropic with a mean annual maximum temperature of 30ºC, minimum temperature of 23.5ºC and relative humidity 75 %.

3.2 Collection of roof water from different types of roofs

Experiment included collection and analysis of roof water from different types of roofs as the rooftop impurities vary with respect to types of roofs. The roof catchment selected were RCC with terracotta paving, clay tiled roofs, new RCC roofs and old RCC roof. For the ease of distinction and description in the literature, the buildings are coded as:

Building 1: Academic block with RCC roof and terracotta tiled paving (RCC+TC)

Building 2: Library building with clay tiled roof

Building 3: Old ladies hostel with RCC roof

Building 4: New ladies hostel with RCC roof

During rainfall events, water falling from the roof was collected using a plastic bucket of 20 litre capacity. Representative samples were taken from this rooftop water for quality analysis in small bottles of size 200 ml.

3.3 Description of the existing micro mesh filter

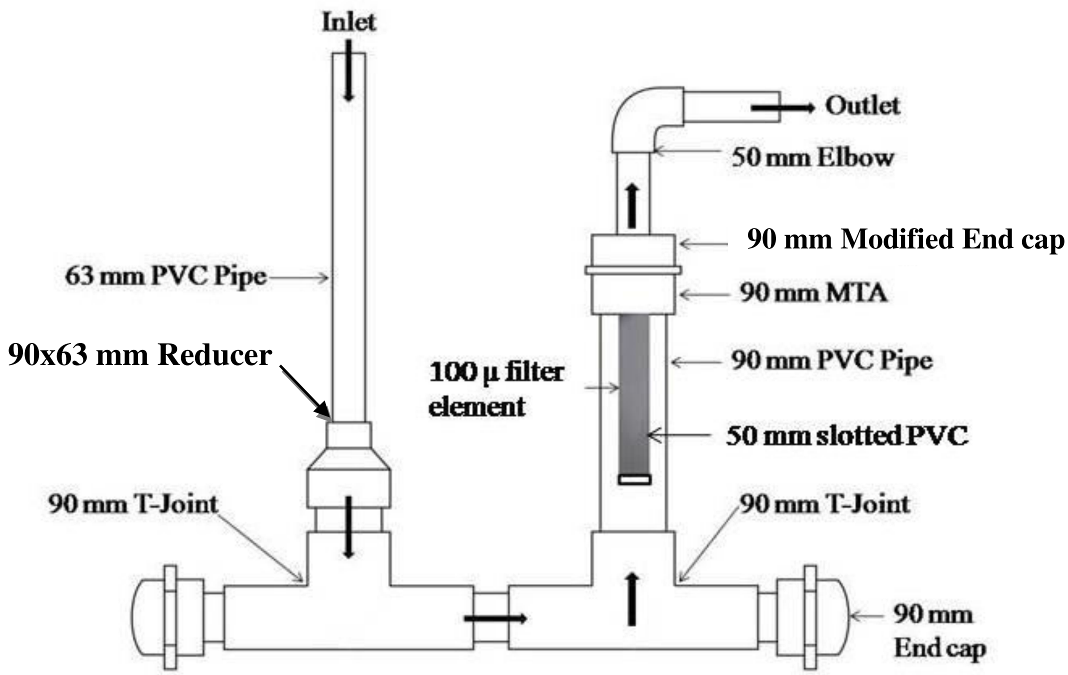
The mesh filter was an upward flow type, constructed using PVC pipes of diameter 90 mm as casing pipe and 100 micron mesh wound on 50 mm slotted PVC as filter element, which is placed inside the casing pipe. The filter element was hung concentrically inside the casing pipe and fixed to the casing by means of threaded end cap. 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.

The region experiences major water scarcity in summer (March to May) due to prolonged summer period and negligible summer showers. Design and arrangement of the existing micro mesh filter is shown in the fig. 3.1.

3.4 Design of sand and charcoal filter

3.4.1 Design and development of the sand filter

Sand filter was designed and constructed using 90 mm diameter PVC pipe of 25 cm long with both ends closed by fine wire mesh of 1mm square. Sand passing through 2 mm and retained on 1 mm was used as the filter media. Sand filter was connected as a secondary filter to the outlet of the micro mesh filter. Outlet of the sand filter was connected to the water storage end of the system. The mesh and sand filter combination was used for the roof water purification. The specifications and arrangement of the sand filter is shown in fig. 3.2 and fig. 3.3 respectively.



Fi

g. 3.1 Existing upward flow micro mesh filter

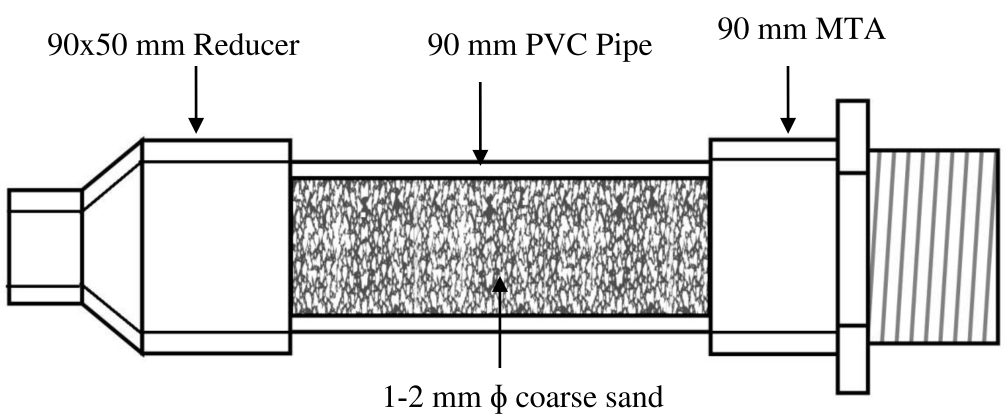


Fig. 3.2 Sectioned view of sand filter

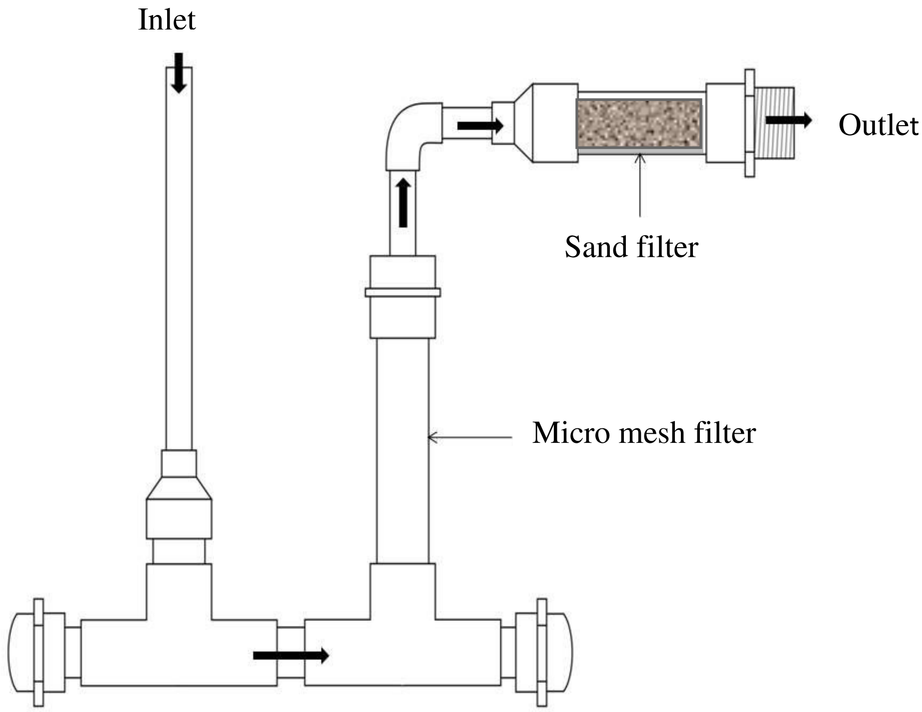


Fig. 3.3 Arrangement of mesh and sand filter

3.4.2 Design and development of the charcoal filter

A charcoal filter was also designed and developed in the similar line as that of the sand filter. A 90 mm diameter PVC pipe of 25 cm long was used as the casing pipe, both ends were closed with fine wire mesh. Further, muslin cloth was also fixed to the inner end of the wire mesh to act as a barrier to prevent the flow of charcoal along with the flow of water. Charcoal was filled in the casing pipe after 24 hours of soaking in water to remove very fine particles which otherwise may go along with the filtered water. Specification of the charcoal filter is shown in the fig. 3.4

The outlet of the micro mesh filter is connected to the inlet of the charcoal filter and the outlet of the charcoal filter is connected to the conveyance pipe leading to the storage tank. Arrangement of the charcoal filter is shown in the fig. 3.5.

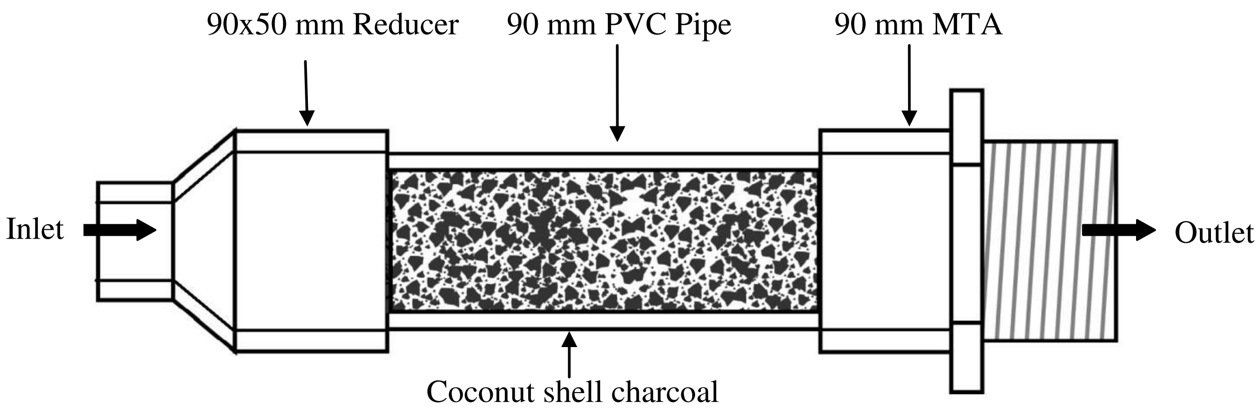


Fig. 3.4 Sectioned view of charcoal filter

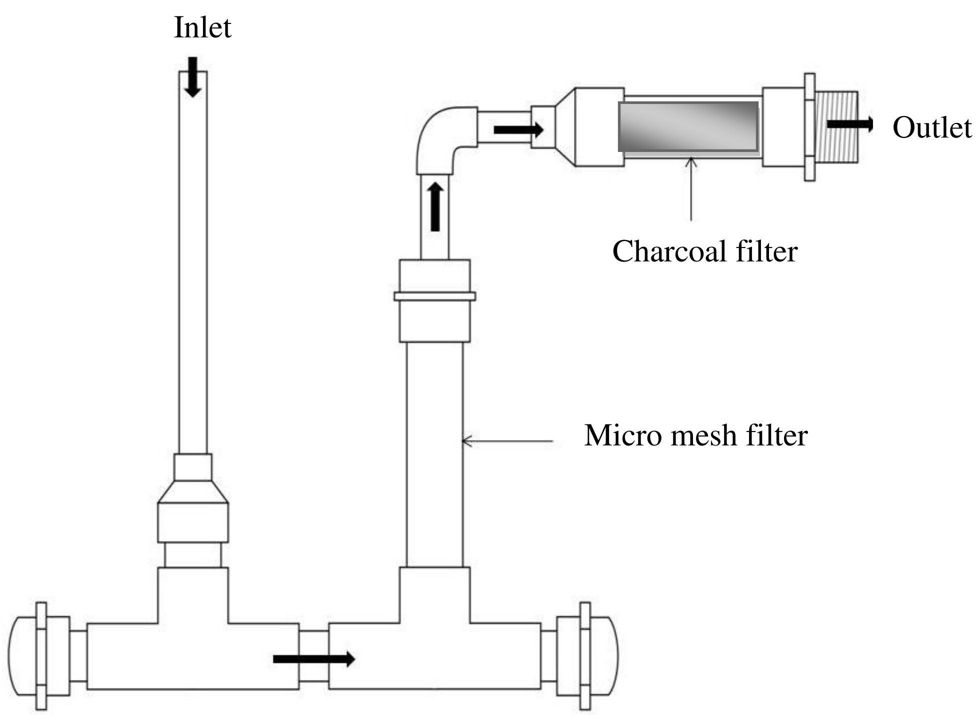


Fig. 3.5 Arrangement of mesh and charcoal filter

3.5 Working of filter systems

Rainwater coming down from the rooftop through the collector system is conveyed to the filter through a 63 mm pipe which then enters a 90 mm pipe where the incoming flow velocity is reduced and the debris are allowed for initial settlement. 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. The filtered water by the mesh filter will flow through the secondary filter having filter media as sand or charcoal. Then the filtered water by different combinations of filters (mesh filter, mesh+sand filter and mesh+charcoal filter) was collected through the outlet pipe connected at the end of filter element. When secondary filters such as sand and charcoal is connected, the micro mesh filtered water will move to the inlet of the secondary filter. After the secondary filtration, purified water will flow to the storage tank. The secondary filter is fitted horizontally and water flows through it in horizontal direction.

As the micro mesh filter unit is designed for the pass of water in upward direction, some of the suspended particles is settled at the bottom of its annular space and will reduce the load of impurities for the mesh filter. Impurities settled at the bottom can be removed by opening the end cap provided at the bottom by flushing. Secondary filters are provided for the finer filtration of the roof water. Impurities remaining after the filtration of micro mesh filter may be removed by the sand or charcoal filter.

Plate 3.1 Experimental setup of roof water purification

3.6 Performance evaluation of the filter system

Various filter units were evaluated for their performances in respect of filtration efficiency of suspended matter, discharge rate, clogging rate and potable water quality parameters. Evaluation was done under natural rainfall and with synthetic roof water. The filter unit was connected to the down pipe of the roof water harvesting system existing for the library building of the KCAET, Tavanur. Inflow and outflow of the filter unit was collected periodically and was subjected to water quality tests.

During the absence of rainfall, synthetic roof water was prepared similar to natural rainfall roof water. For this, natural rooftop water falling down the roof was collected and the level of suspended impurities was determined through laboratory test (Gravitational method).The main suspended impurities in roof top rainwater was moss. Hence, the moss was mixed with pure water in varying concentrations, to give impurities concentrations on higher and lower side with that of natural concentration.

The synthetic roof water was fed into the down pipe leading to the filter and outflow was collected in sampling bottles. These samples were tested for various water quality parameters viz, suspended solids, turbidity, pH, electrical conductivity and microbial load. The synthetic roof water is shown in the figure.

Plate 3.2 Synthetic roof water

3.7 Preparation of synthetic roof water

Synthetic roof water was prepared with impurities level as close to natural roof water. Main impurities present in the natural rooftop water, the vegetative growth by mosses, were collected from different roof catchments viz, academic block, library, old ladies hostel and new ladies hostel. In order to maintain same dry matter impurities level in the synthetic roof water, as that of the natural roof water, the mosses collected from the roof were oven dried and the same dry matter concentration was maintained as that of the natural rain rooftop water. While preparing the synthetic roof water, different impurities concentrations were maintained

3.8 Estimation of water quality parameters

The quality of filtered water is mainly assessed to know the potability of the roof water. Water quality parameters obtained through the test were compared with that of the threshold levels as specified by WHO and BIS.

3.8.1 Physical analysis through water quality analyzer

A water quality analyzer, SYSTRONICS WATER QUALITY ANALYSER 371 was used to carry out the physical analysis of the roof 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 analyser provides both automatic and manual temperature compensation. Calibration / standardization of the instrument is 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 re-calibrating 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 include temperature, pH, colour, turbidity, odour and electrical conductivity. Rainwater collected from roof was used to carry out the physical test.

Plate 3.3 Systronics water quality analyzer

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 value of drinking water is 6.5 to 8.5. pH is determined by 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 / silver chloride electrode from the solution under study. The Ag / AgCl electrode is connected to a lead cable terminated with some connector that can hook up to a special voltmeter, 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 the internal solution. A second point is obtained by connecting to a reference electrode, immersed in the studied solution.

Plate 3.4 pH electrode

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.

Plate 3.5 Conductivity cell

3. Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (total suspended or dissolved solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Suspension of particles in water interfering with passage of light is also called turbidity. Turbidity of water is responsible for the light to be scattered or absorbed rather than its straight transmission through the sample, it is the size, shape, and refractive index of suspended particulates rather than the total concentration of the latter present in the water samples that are responsible for turbidity. The units of turbidity are commonly called Nephelometric Turbidity Units (NTU). Many drinking water utilities strive to achieve levels as low as 0.1 NTU, but up to 5 NTU is also allowable for drinking purposes.

3.8.2 Total suspended solids by gravimetric method

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 105º C.

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

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 3.6 Gravimetric experimental setup

3.8.3 Analysis of microbial load

Two tests were conducted to determine microbial load on the rooftop water such as Biochemical Oxygen Demand (BOD) and total coliforms. The tests were undertaken at the Environmental Engineering laboratory of NIT Calicut, Kerala. Tests were successfully completed with the support of lab technical personnel. Procedures adopted in the case of different analysis are presented below (IS: 5611 - 1987).

1. Biochemical Oxygen Demand (BOD)

BOD is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific period of time. It is used as a measure of the degree of water pollution. The test consists in taking the given sample in suitable concentrations in BOD bottles. Two BOD bottles are taken for each concentration and three concentrations are used for each sample. One set of bottles are incubated in a BOD incubator for 5 days at 20^0 C. The initial dissolved oxygen content (D_1) in the other set of bottles will be determined immediately. At the end of the 5^{th} day, the dissolved oxygen content (D_2) in the set of bottles (kept in the incubator) was determined. The specific procedure of the test is given below.

1. Five litre of distilled water was taken in a flask.
2. Added 1 ml each of phosphate buffer, magnesium sulphate, solution calcium chloride solution and ferric chloride solution for every litre of distilled water.
3. Saturated the dilution water in the flask by aerating with a supply of clean compressed air for 30 minute.
4. Sample is taken in the required concentrations (1, 2.5 and 5 %).
5. Added the required quantity of the sample (calculated for 650 ml dilution water) into a 1000 ml measuring cylinder and made the dilution water up to the 650 ml mark.

6. The contents were mixed in the measuring cylinder and filled the solution into two BOD bottles, one for incubation and the other for determination of initial dissolved oxygen in the mixture.
7. BOD bottles were placed for incubation in a BOD incubator for 5 days at 20^0C and determined the initial dissolved oxygen content.
8. Finally the BOD of the sample was calculated using the equation.

$$\text{BOD in mg/l} = \frac{D_1 - D_2}{P} \qquad \text{...... 3.2}$$

Where,

P = Decimal fraction of sample used

D_1 = Initial dissolved oxygen of diluted sample, mg/l

D2 = Dissolved oxygen of diluted sample at the end of 5^{th} day of incubation, mg/l

If concentration of the sample is 1 % then $P = \frac{1}{100}$

2. Total coliform test

The coliform group of bacteria has been considered as the indicator organisms for faecal pollution in water. The E-coli group of organisms further confirms the presence of faecal matter in the water tested. The coliform group comprises all of the aerobic and facultative anaerobic gramnegative, non spore forming, rod shaped bacteria. The water is considered to be safe when these organisms are absent. The reagents used in the total coliform test are Laurly tryptose broth and Brilliant green lactose bile broth. The procedure adopted for the test is given below.

1. Prepared the sterilized media necessary for the bacteriological test and kept them ready in test tubes containing Durham tubes.
2. Inoculated the sample in an exponential order i.e. 10.0, 1.0 and 0.1 ml in five tubes each of lauryl tryptose broth under complete aseptic conditions.
3. Incubated all the tubes at 35^0C and after 24 hour all the tubes were examined for gas formation.

4. The tubes containing the gas are marked positive and were taken out of the incubator for further analysis. The remaining tubes were incubated at 35^0 C for another 24 hour.
5. At the end of 24 hour, the tubes were examined for gas formation. The negative tubes were further incubated for another 24 hour and the presence or absence of gas was noted.
6. The gas production after 24 hour, confirms the presence of E-coli organisms or other coliforms.

3.9 Filtration rate of different filter systems

The discharge rate and filtration rate of different filters were determined by collecting the filtered water from the filter outlet for a known time by keeping the head constant. Filtration rate is calculated using the following relation.

$$R_f = \frac{V}{t \times A} \qquad \text{….. 3.3}$$

Where,

R_f is the filtration rate, $m^3/min/m^2$

V is the volume of water collected, m^3

t is the duration of collection, min

A is the surface area of the filter, m^2

3.10 Estimation of filter efficiency

The concentrations of suspended solids in the water before filtering and after filtering are found out as per the procedure mentioned in 3.8.2. The efficiency of the filters has been determined by the following equation.

$$E = \frac{S_b - S_a}{S_b} \times 100 \qquad \text{….. 3.4}$$

Where,

E = Efficiency of the filter, %

S_b = Suspended solids before filtering, mg/l

S_a = Suspended solids after filtering, mg/l

Results and discussions

CHAPTER 4

RESULTS AND DISCUSSION

The performance evaluation of different filter systems in the purification of rooftop rain water is presented here. Various experiments conducted are the evaluation of roof water quality parameters of different types of roofs and performance evaluation of different types and combinations of filters.

4.1 Effect of roofing material on quality of roof water

Analysis of roof water collected from the different roofing materials have shown that the concentration of impurities varies with respect to types of roof and variations in rainfall characteristics. Close observations of the impurities have indicated that major portions of the impurities are constituted by moss grown on the roof. The quality parameters such as pH, electrical conductivity, turbidity and suspended solids in the roof water from different roof tops are shown in the table below.

4.1.1 pH of the roof water samples

The pH of roof water collected from different buildings with different roofing materials is tabulated and is shown in table 4.1. pH values of the roof water samples collected on four different dates from the four different buildings under study are presented in the table. In general, the pH values are very close to 7, indicating that the rain water and there by the roof water in this locality is neutral. Since the study area is rural, the results tally with the findings of many other studies (Jamal *et al.,* 2009; Narasimha Rao *et al*., 2011; Young *et al*., 2012).

It can be seen that the average pH of the roof water harvested from four different building through different rainfall events are ranging from 6.1 to 7.1. No appreciable difference in pH between the RCC and clay tiled roof was also seen. As pH values in both the cases were very close to neutral values, both roof catchments can be recommended for roof water collection from drinking purpose. Some studies have reported increase in pH for the water collected from roof compared to that of ambient (direct) rainwater. One sample from building 4 (new RCC) was of considerably acidic in nature. This may be due to the temporary existence of some acidic material on the roof.

Table 4.1 pH of the rooftop water samples

Date	**Building 1** (RCC+TC)	**Building 2** (Clay tiled)	**Building 3** (Old RCC)	**Building 4** (New RCC)
11/06/2013	6.65	6.78	6.94	4.04
28/06/2013	7.08	7.01	7.25	6.97
04/07/2013	6.68	7.26	7.04	6.18
17/07/2013	7.01	7.26	7.04	7.12

4.1.2 Electrical conductivity

The electrical conductivity (EC) of the collected roof water samples determined by water quality analyzer is shown in table 4.2. Conductivities of samples were ranging from 20-1700 µS/cm. Wide variations for EC was seen between the rainfall events and types of roof. These variations may be due to the varied presence of charged ions in the impurities in the atmosphere and on the roof. EC corresponding to the rainfall event on 11.06.13 was considerably lower in the case of all the roofs. The reason could be the collection of roof water during continuous rainy period, which may yield better quality of water from the atmosphere and that from roof. The rest of the samples were collected after a dry spell of few weeks.

Table 4.2 Electrical conductivity of samples in µS/cm (cell constant = 1.166)

Date	**Building 1** (RCC+TC)	**Building 2** (Clay tiled)	**Building 3** (Old RCC)	**Building 4** (New RCC)
11/06/2013	23.4	25.7	42.6	72.7
28/06/2013	630	1150	1130	1490
04/07/2013	710	802	1030	975
17/07/2013	385	975	939	1630

4.1.3 Turbidity

Turbidity is widely used in water quality guidelines for indirect measurements of particles in the water. Turbidity of collected samples was tested and the values were varying in the range of 0.5 to 15 NTU. Turbidity values vary significantly between the roofing materials considered under the study (Table 4.3). Between rainfall events too turbidity varied considerably. The occurrence of this turbidity variation may be due to the variations in the presence of moss content as well as their susceptibility for dislodgement. It has been reported that particulate matter washes off from smoother surfaces more rapidly than it does from rougher surfaces (Egodawatta *et al*., 2009). According to the USEPA primary drinking water standards for systems using conventional or direct filtration, turbidity should never be above 5 NTU. Therefore, in majority of the samples, the turbidity values were above the allowable limits.

Turbidity values were considerably higher in the case of tiled roof compared to RCC roofing. The findings go in conformity with the reported literatures (Wilson, 2010; Kondal *et al*., 2011).

Table 4.3 Turbidity of samples in NTU

Date	**Building 1** (RCC+TC)	**Building 2** (Clay tiled)	**Building 3** (Old RCC)	**Building 4** (New RCC)
11/06/2013	13	0.59	1.3	0.59
28/06/2013	1.8	4.5	0.73	2.7
04/07/2013	15	7.3	9.3	2.1
17/07/2013	9.7	3.6	3.0	3.1

4.1.4 Total suspended solids

The selected samples were analyzed for suspended solids by gravimetric method and the values are ranging from 100- 600 mg/l (table 4.4). Different rainfall events showed different values of suspended solids. Between roofs, there were variations, but, that was not consistent. Based on the turbidity and suspended solids concentrations in the roof water harvested after the first-flush, it can be seen that all the samples were not meeting the potable standards. Thus, treatment is a must to make it potable. The importance of purification of roof water has been highlighted by this result.

Table 4.4 Suspended solids of given samples in mg/l

Date	**Building 1** (RCC+TC)	**Building 2** (Clay tiled)	**Building 3** (Old RCC)	**Building 4** (New RCC)
11/06/2013	290	250	110	340
28/06/2013	100	200	200	160

04/07/2013	300	300	500	170
17/07/2013	200	100	120	600

Fig. 4.1 pH of different roof water samples

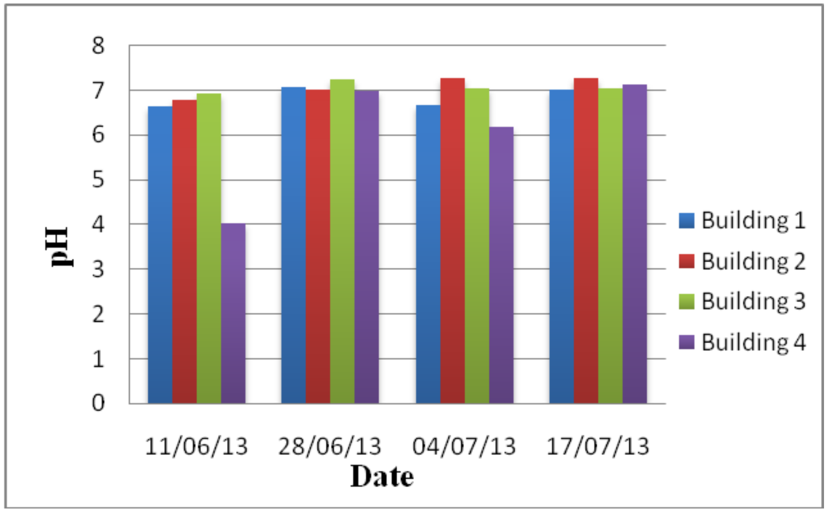


Fig. 4.2 Turbidity of different roof water samples

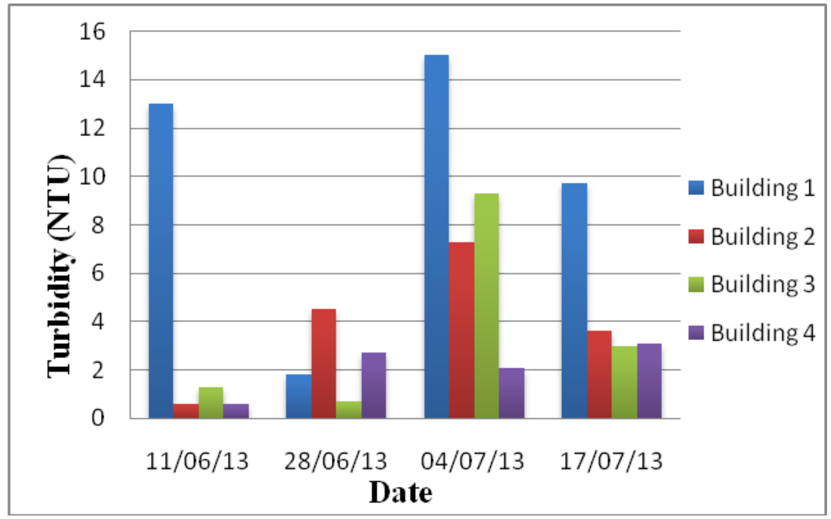


Fig. 4.3 EC of different roof water samples

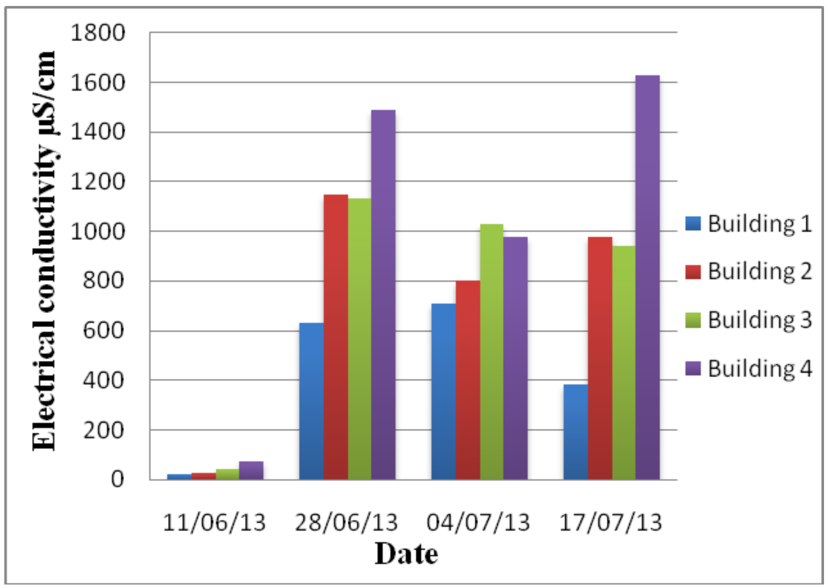
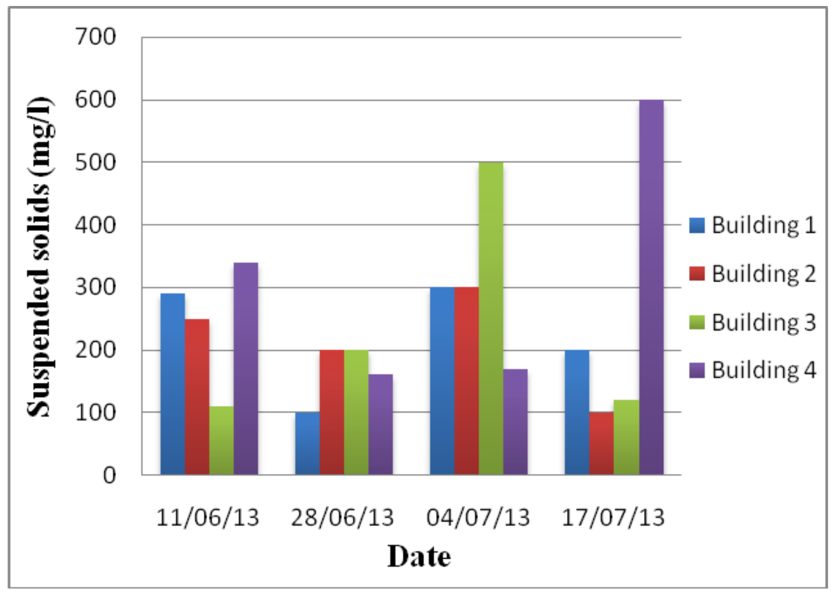


Fig. 4.4 Suspended solids of different roof water samples



4.2 Evaluation of micro mesh filter under natural rainfall

The micro mesh filter was tested under natural rainfall conditions. After connecting the mesh filter to the roof of the library building of the campus, the inflow and out flow were collected in sampling bottles and analyzed by water quality analyzer and gravimetric method. The results of evaluation of roof water quality parameters of the inflow and outflow water of the mesh filter is presented in fig. 4.5, 4.6 and 4.7. The mesh filter is primarily designed to remove the suspended impurities in the rooftop water. There is marked reduction in the turbidity values obtained from the water quality analyser. It is also observed that the mesh filter changes the values of pH and conductivity of the outflow water. After the filtration, the pH, conductivity, turbidity of the roof water is in the desirable range.

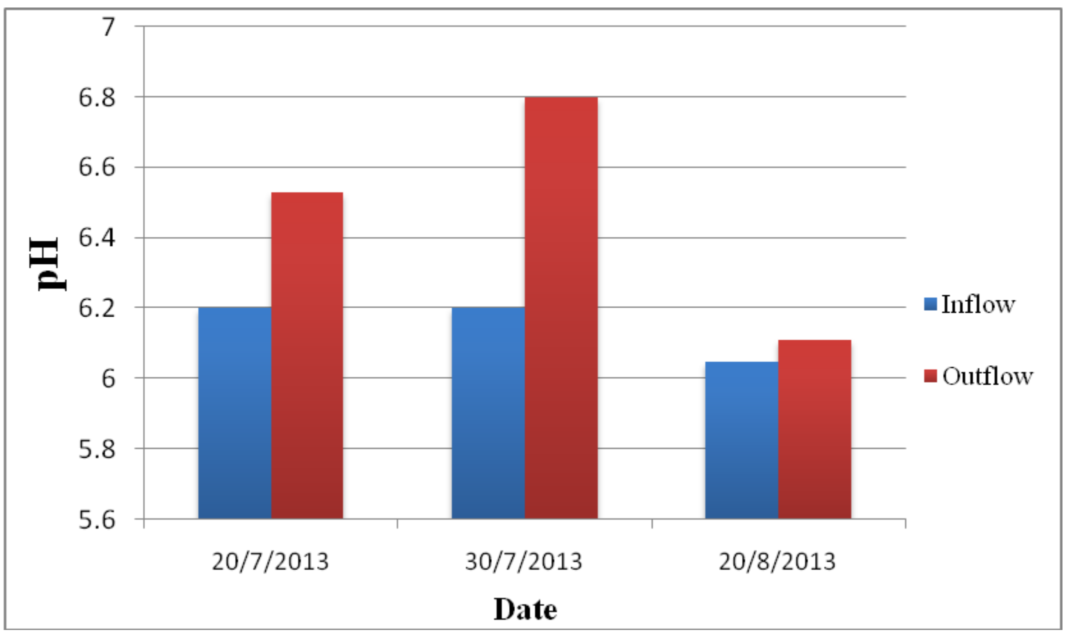


Fig. 4.5 pH of the inflow and outflow of the mesh filter

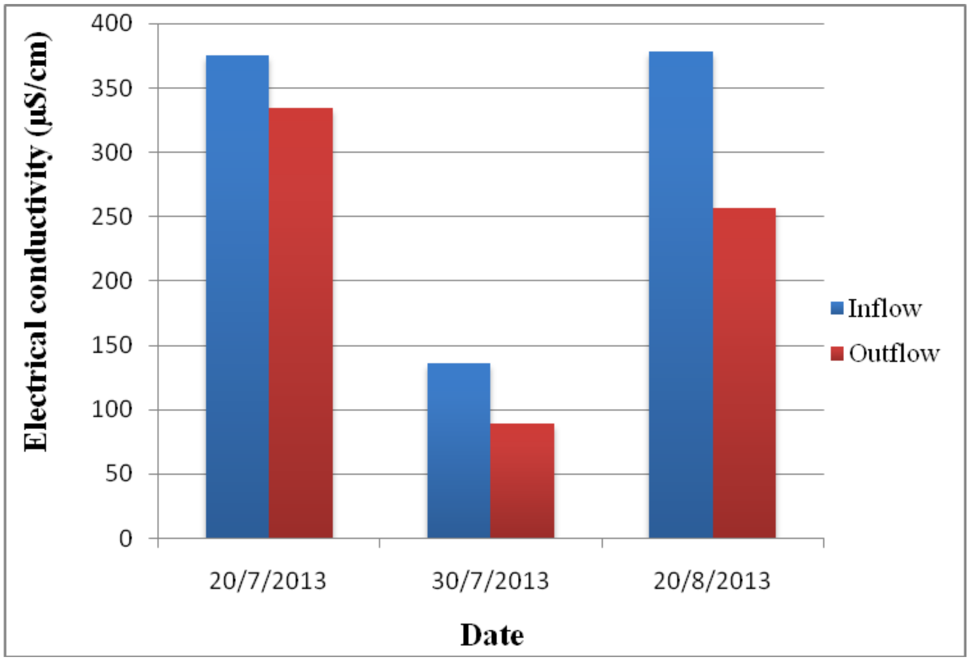


Fig. 4.6 EC of the inflow and outflow of the mesh filter

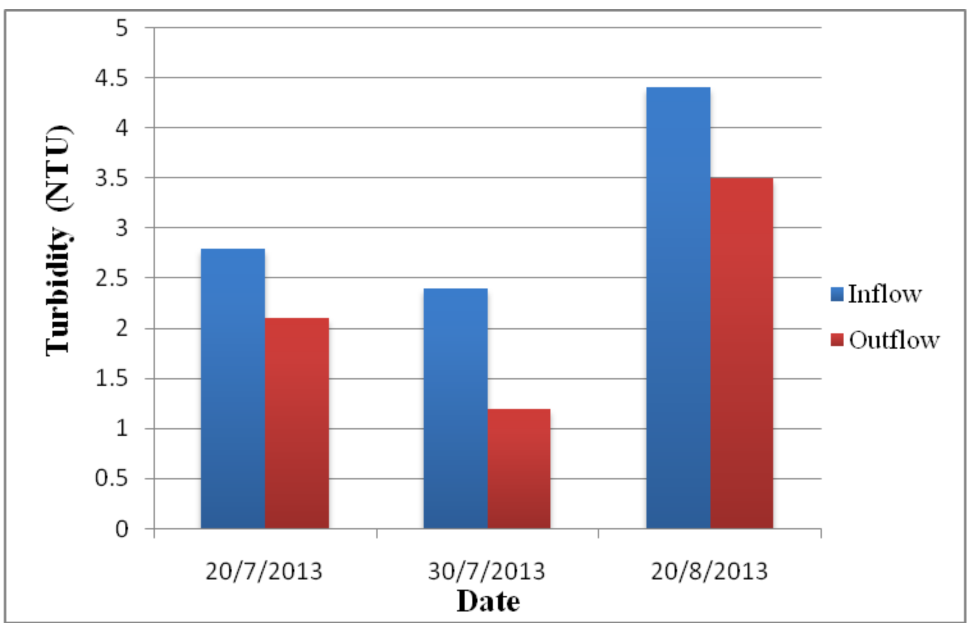


Fig. 4.7 Turbidity of the inflow and outflow of the mesh filter

4.3 Evaluation of suspended solids by gravimetric method

Evaluation of suspended matter has been carried out by gravimetric method to get more reliable results. Impurity level of inflow was found to vary in the range of 330 to 450 mg/l for the tiled roof after the first flush (removal of initial high impurities). Concentration of impurities in the outflow was in the range of 50-85 mg/l. This shows that the filter reduces the impurities load to about 15 % or the removal of impurities is about 85 %. After the filtration, the suspended matter impurities came down to a level acceptable by EPA potable standards.

Analysis of roof top water has shown that the maximum impurity level was about 600 mg/l. The major portions of impurities are constituted by moss presented on the roof. Suspended solids in the inflow and outflow water are shown in the figure 4.8. The result indicates that the impurities in the outflow shows a drastic reduction compared to inflow.

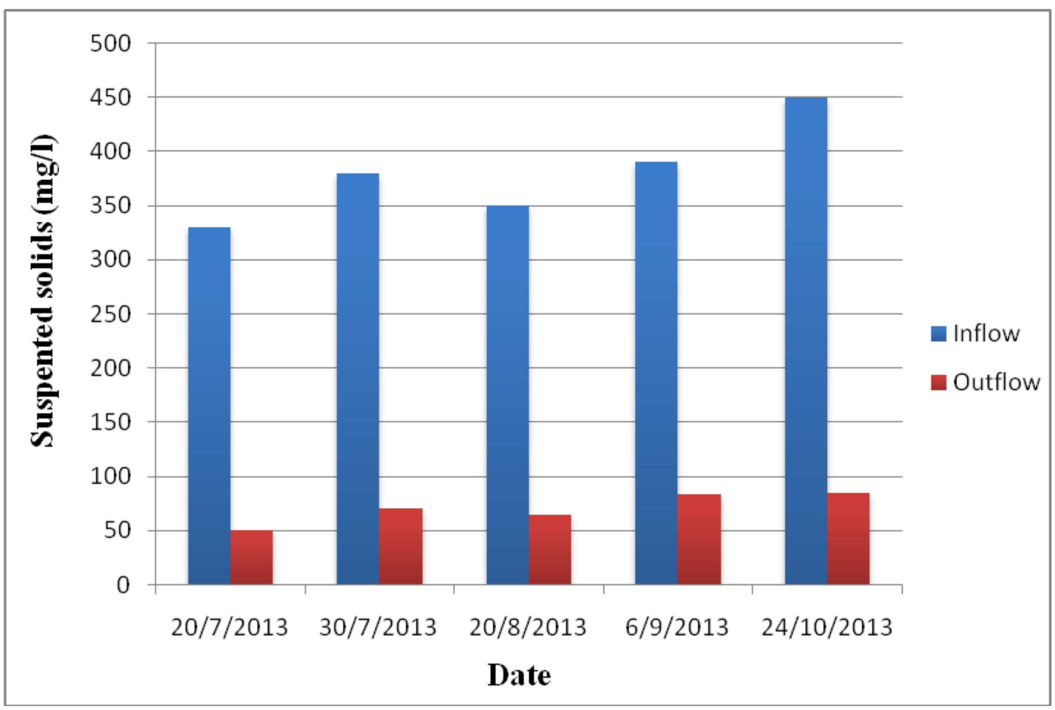


Fig. 4.8 Suspended solids in the inflow and outflow water

4.4 Characteristics of synthetic roof water

Moss was collected from three different roofs viz., clay tiled, RCC and asbestos. Synthetic roof water was prepared to have the concentration of suspended impurities as close to that of natural rainfall roof water on dry matter basis. On dry basis, the impurities concentration of natural roof water was in the range of 400 to 800 mg/l after first flush. In order to prepare synthetic roof water, the water content of moss collected from different roofs were determined through oven drying and the dry matter content was estimated. Water content of moss from different roof was 11 % when the sample was collected on a dry day after a considerable spell of rainfall event. The synthetic roof water was similar to that of natural roof water in appearance. The characteristics of inflow and outflow of the synthetic roof water was analysed as that of the natural roof water and the results are presented below.

Table 4.5 Moisture content of moss collected during dry period

Roof type	Initial weight (g)	Final weight (g)	Moisture content Dry basis (%)	Dry matter fraction
Clay tile	5	4.5	11.1	0.9
Concrete	5	4.5	11.1	0.9
Asbestos	5	4.5	11.1	0.9

4.4.1 pH of samples

pH values of inflow water was ranging from 5.02 to 5.91 and is shown in fig. 4.9. No correlation was observed between pH and the moss concentration. Small improvement for pH of roof water was observed when it passes through the mesh, sand or charcoal filter.

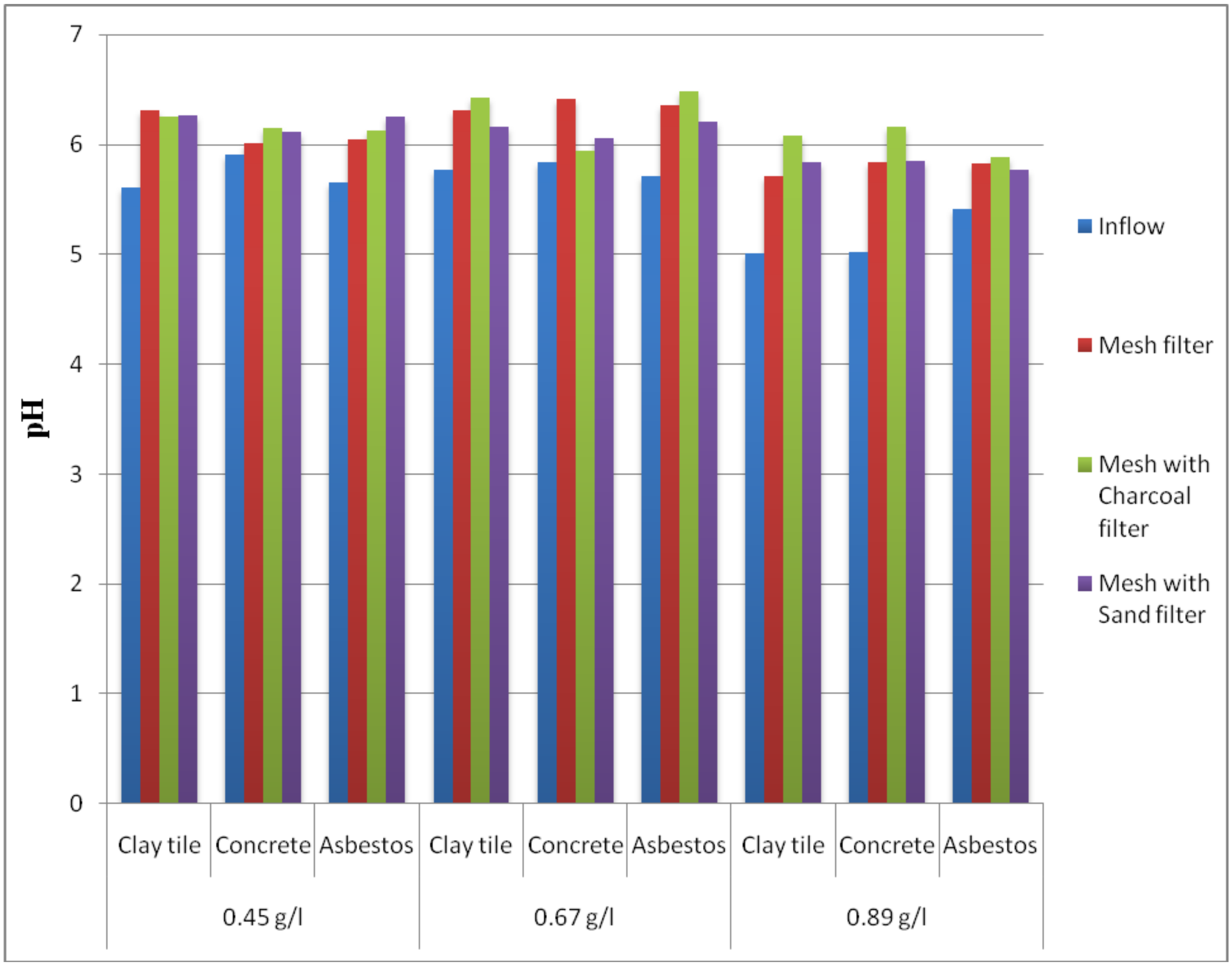


Fig. 4.9 pH of inflow and outflow of synthetic roof water

4.4.2 Electrical conductivity

EC of the inflow and outflow of synthetic roof water was also measured. The range of EC of inflow water was 250-460 µS/cm (Fig. 4.10). EC values of the outflow of mesh filter were in the range of 69-176 µS/cm. A marked reduction in EC has been observed when the sample passes through mesh filter. When mesh filter and charcoal filter is used in combination, the EC value reduces to the range of 69-98 µS/cm. In the case of sand filter, the EC value laid between the range 72-120 µS/cm.

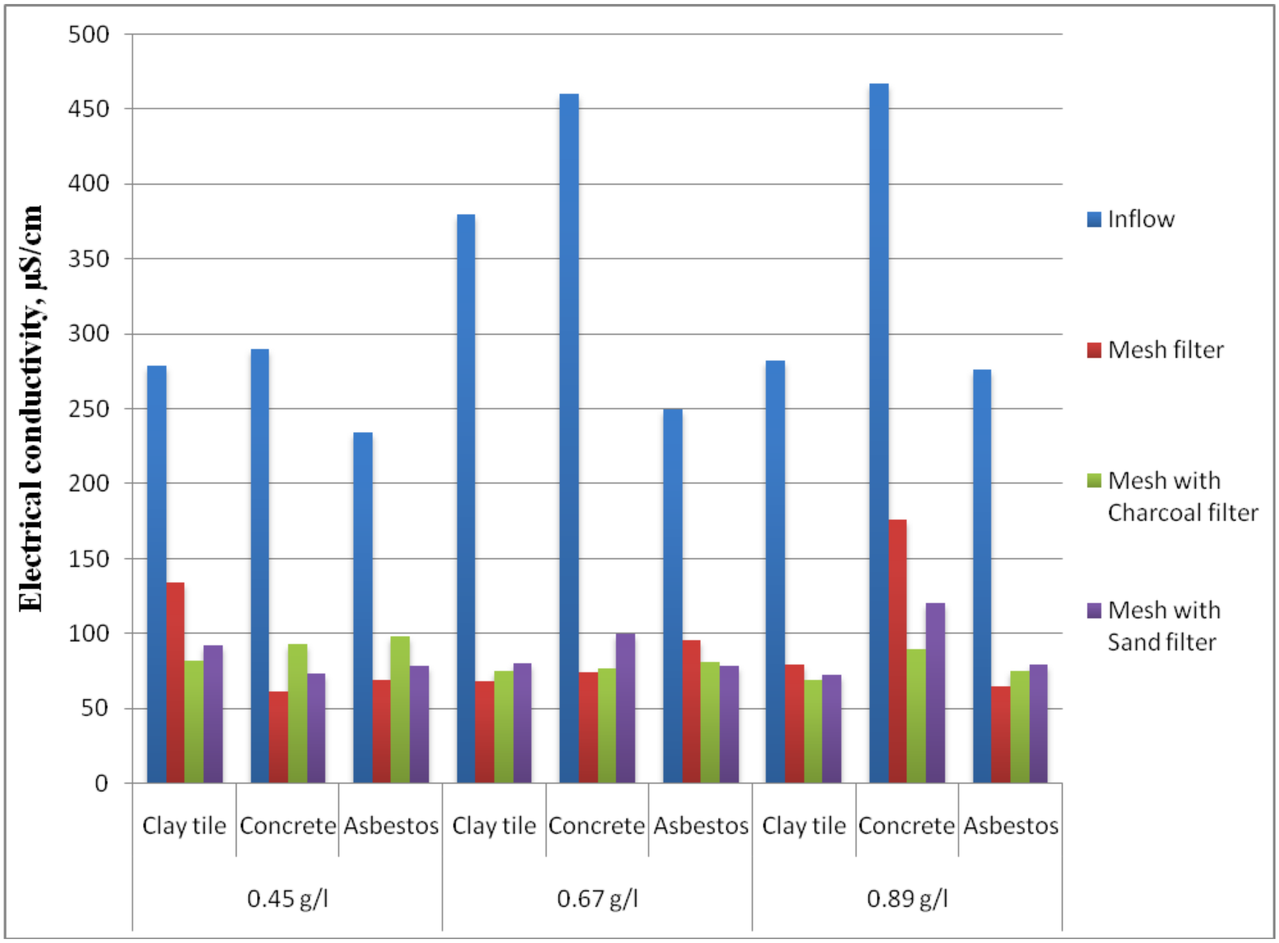


Fig. 4.10 EC of inflow and outflow of synthetic roof water

4.4.3 Turbidity of samples

Turbidity values of inflow and outflow of the synthetic roof water is presented in fig. 4.11. The range of turbidity of the inflow was 29-59 NTU. The reduction in turbidity was very significant in all the filter combinations. The reduction in turbidity was to the order of about 90 %. Between filter combinations, the change in turbidity was not very distinct.

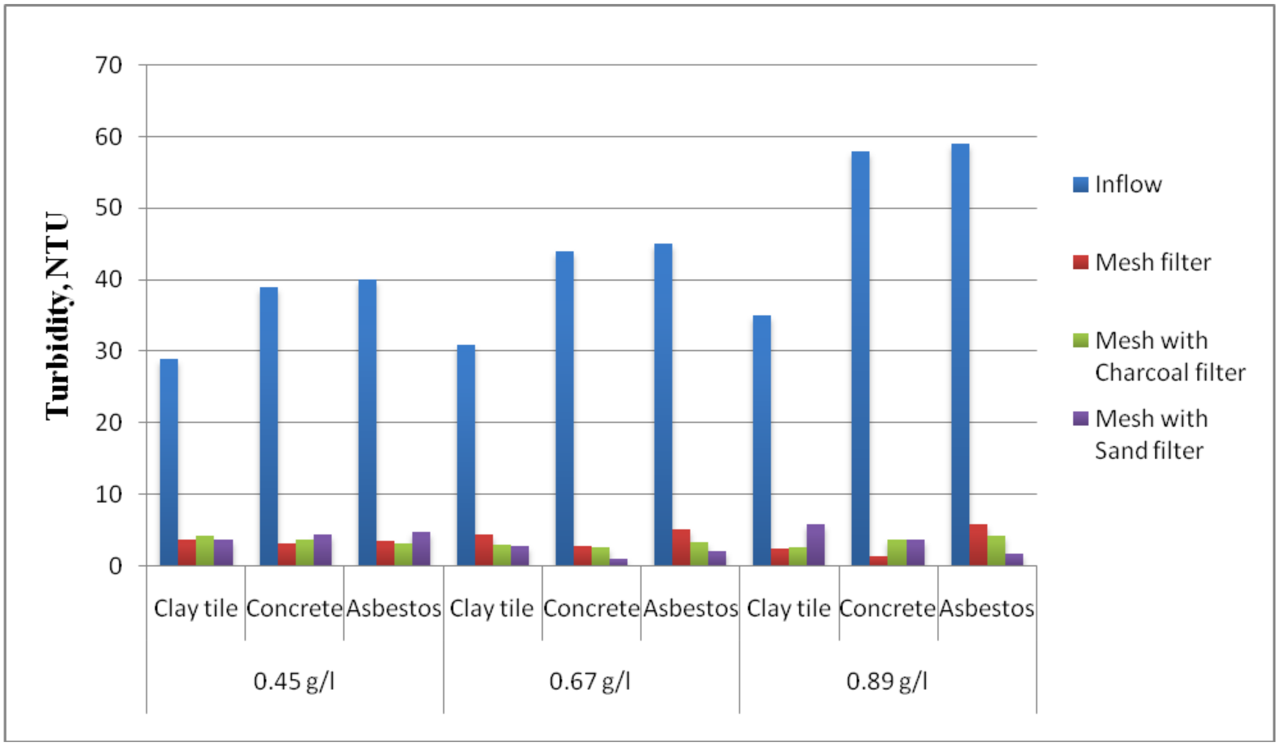


Fig. 4.11 Turbidity of inflow and outflow of synthetic roof water

4.4.4 Suspended solids_Gravimetric method in mg/l

The suspended sediment concentration of the inflow and outflow of the synthetic roof water was analysed by gravimetry and the results are shown in the fig. 4.12. About 90 % reduction in suspended sample can be observed in the case of all the filters. The result appears to be very encouraging. Between different filter combinations, there were no markable changes in the reduction of suspended impurities.

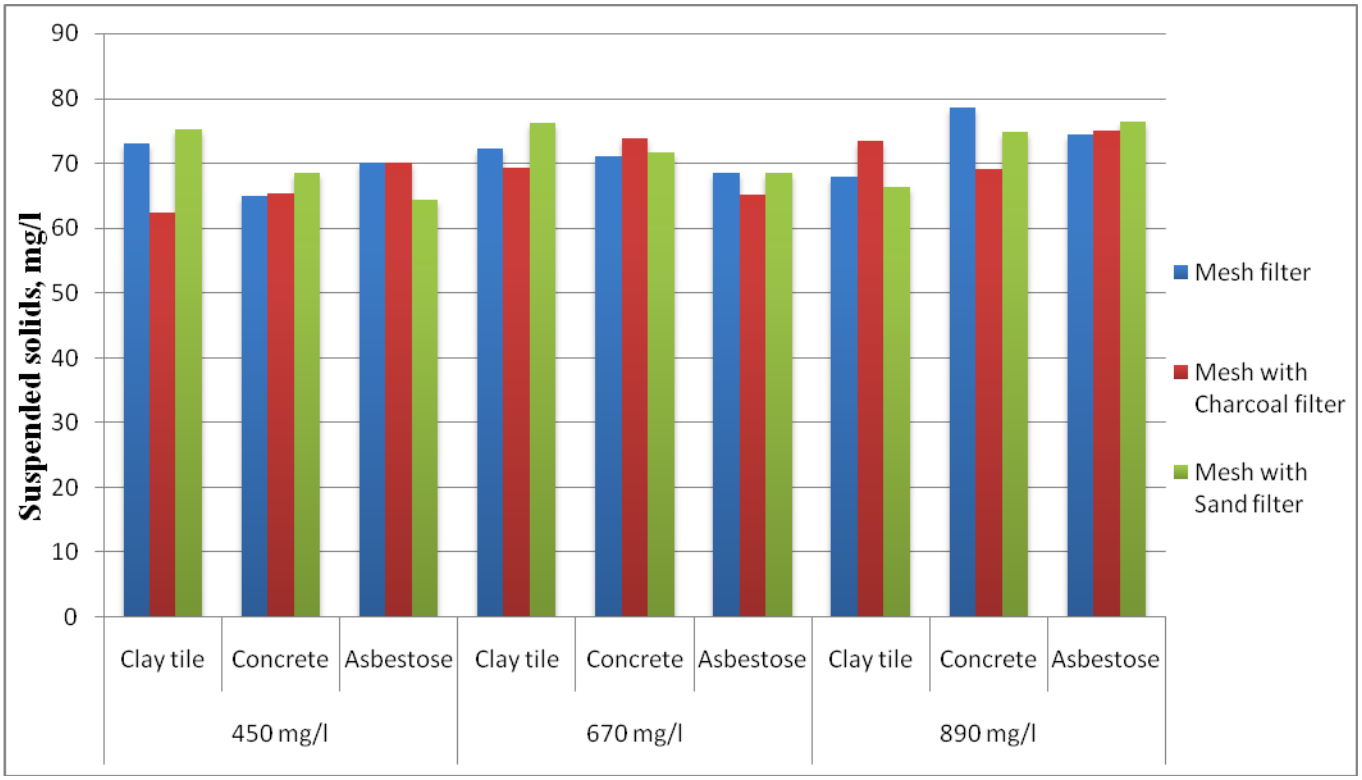


Fig. 4.12 Suspended solids of synthetic roof water

4.5 Microbial activity on filtered water

The microbial activity was determined through biochemical oxygen demand (BOD) and coliforms tests. Both tests were successfully completed with reliable results.

4.5.1 Biochemical oxygen demand (BOD)

The BOD of polluted water is the amount of oxygen required for biological decomposition of dissolved organic solids to occur under aerobic conditions and at a standardized time and temperature. The results of BOD analysis of the roof water samples are shown in fig. 4.13. BOD of the inflow synthetic roof water varied from 170 to 300 mg/l. BOD of the filtered water was very low compared to that of inflow. Reduction in BOD indicates the removal of organic matter from the impure water. All filter combinations have found to remove the organic impurities significantly. Between filter combinations, there were no significant variations.

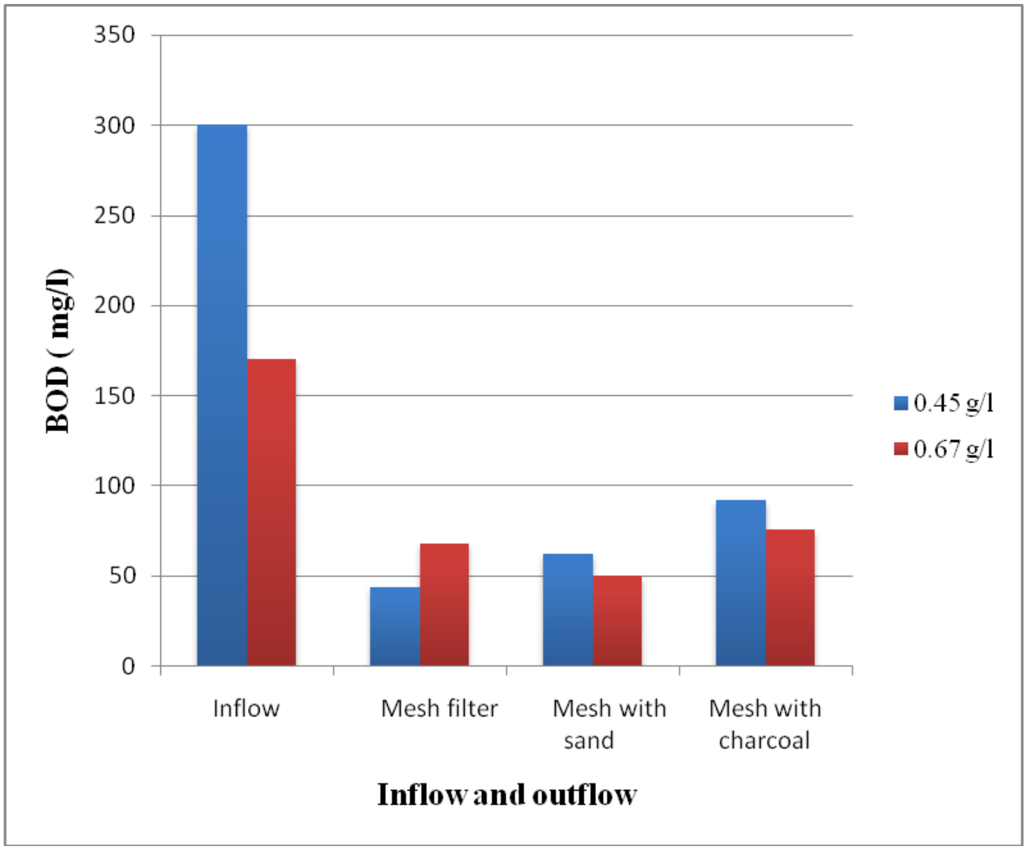


Fig. 4.13 BOD of inflow and outflow of the filters

4.5.2 Total coliform test

The coliform group of bacteria has been regarded as the organisms for faecal pollution in water. The total coliform test was carried out as per the procedure described in section and the results are presented in table 4.6. There were no colifirms (0/100ml) in the filtered water after 24 hour incubation period. Whereas, in the inflow, coliforms were detected. According to the BIS 10500 of 2012 and WHO water quality standards, the coliform result was within the permissible limit. So the water can be used for drinking purposes.

Table 4.6 Coliforms count in the roof water samples

Sample name	Volume of sample incubated in ml															Total no of positive tubes	MPN
	10	10	10	10	10	1	1	1	1	1	0.1	0.1	0.1	0.1	0.1		
0.45 g/l(Clay tile)																	
Inflow	3	2	2	1	3	2	2	1	1	1	1	0	1	1	0	13	21
Mesh filter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesh with sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesh with charcoal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.67 g/l(Asbestos)																	
Inflow	2	2	2	1	1	2	2	1	1	0	2	0	1	0	0	11	17
Mesh filter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesh with sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesh with charcoal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.6 Filtration rate of different filter systems

Rate of filtration is an important characteristics of filters used in rain water harvesting systems. Considerable filtration rate has to be there in order to collect required quantity of water in a short span of time as the rain lasts only for short durations. The rate of filtration was determined by measuring the volume of outflow for a specified period of time. The filtration rates of different filters used in the study are shown in the table 4.7.

The discharge and filtration rates were highest in the case of mesh filter. The combination of mesh and sand filter gave the minimum rate of filtration. In all the cases, the filtration rate was sufficient for a domestic roof water harvesting system. The mesh filter had 3.1 l/s discharge and 3.83 $m^3/min/m^2$ filtration rate. In the case of primary and secondary filter combinations, filtration rate was worked out based on the cross sectional area of the secondary filter.

Table 4.7 Filtration rate of different filter systems

Type of filter	Discharge (l/s)	Filtration rate ($m^3/min/m^2$)
Mesh filter	3.10	3.83
Sand filter	0.70	6.60
Charcoal filter	0.95	9.42

4.7 Filtration efficiency of mesh filter in natural rainfall conditions

The efficiency of suspended matter removal by the micro mesh filter was quantified by the equation 3.4 and is presented in table 4.8. The variation of filtration efficiency was ranging from 78.6 to 84.0 %. This efficiency values are appreciable in the light of the simplicity of the filter device developed and also while comparing with the performance of other sand and charcoal filters reported in many research studies (Harishankar *et al*., 2010; Ronan *et al*., 2012). The ease of cleaning feature of the mesh filter makes it more attractive and acceptable.

Table 4.8 Reduction in the impurity concentration

Sl no:	Suspended solid before filtering (mg/l)	Suspended solid after filtering (mg/l)	Efficiency (%)	Average Efficiency (%)
1	330	50.0	84.0	81.3
2	380	70.0	81.5	
3	350	65.0	81.4	
4	392	83.2	78.6	
5	450	85.0	81.1	

4.8 Filter efficiency of different filter combinations under synthetic roof water

The filtration efficiency for the two secondary filter combinations have been evaluated extensively using synthetic roof water and is presented in table 4.9. It is found that there is a marked reduction in the concentration of impurities. The reduction in impurities ranges from 84 to 86 %. The mesh filter in isolation or in combination with sand or charcoal did not show significant variation in their filtration efficiency. Mesh with charcoal filter combination gave maximum filtration efficiency (85.5 %).

Table 4.9 Filtration efficiency of different filter combinations

Filter combinations	Roofing material	Efficiency (%)	Average Efficiency (%)
Mesh with Charcoal filter	Clay tile	86.31	85.5
	Concrete	85.63	
	Asbestos	84.59	
Mesh with Sand filter	Clay tile	83.47	85.0
	Concrete	84.92	
	Asbestos	85.87	
Mesh filter	Clay tile	83.9	84.7
	Concrete	85.7	
	Asbestos	84.6	

4.9 Best filter combination

It was found that charcoal filter with mesh filter combination results is the maximum filtration efficiency. At the same time, the improvement of filtration efficiency compared to the sand and mesh filter combination was very marginal. Hence, considering the ease of maintenance, a mesh and sand filter combination has been recommended for the purification of roof water. The specification and arrangement of the filter combination is shown in fig. 3.2 and fig. 3.3.

Summary and conclusion

CHAPTER 5

SUMMARY AND CONCLUSIONS

Rooftop rain water harvesting has tremendous potential in solving the water scarcity of a region, especially the domestic one. As roof water carries impurities, purification of this water is a must to make it acceptable for domestic use. Commonly used purification method is a sand and gravel filter fitted to the top of the storage tank. The sand and gravel media will get clogged easily and its cleaning is very difficult. Due to the filter clogging, majority of the roof water harvesting systems are dysfunctional after a very short span of life of their commissioning. In this context, an alternative filter system with high filtration efficiency and easy to clean provision will be a great boon in solving the roof water harvesting issue. Therefore, a study has been carried out with the following specific objectives:

- To evaluate the performance of a micro mesh filter for roof water harvesting
- To modify the design of the existing filter system
- To evaluate the filtration efficiency of the modified filter system

As part of the study, quality of roof water from different kinds of roofing materials has been conducted and the parameters viz. pH, EC, turbidity and suspended matters have been evaluated. Result showed that pH value from tiled and RCC building was very close to 7 indicating neutrality. Variations in pH between rainfall events were also not prominent. In the case of EC value, newly constructed RCC building gave considerably higher values compared to old RCC and tiled building. Presence of ions in fresh Portland cement could be the reason. However, in all cases the EC values were in the potable limits recommended by national and international agencies. In the case of turbidity, the water samples had slightly higher levels than the values prescribed for drinking water standards. In the case of suspended solids, the values were higher than that is permissible for drinking water standards.

Evaluations of the performance of the micro mesh filter showed that it improves the pH values of outflow water closer to 7.0 and also it reduces the EC and turbidity values. In the case of suspended impurities, the reduction of impurities is to the tune of 85 % and this result is very encouraging. Evaluation of the sand and charcoal filter combinations with mesh filter showed a great reduction in EC values compared to the case of mesh filter alone. In the case of pH, turbidity and suspended solids their values did not show any considerable changes in comparison with the unitary mesh filter.

The BOD test with the outflow of synthetic roof water resulted in the marked reduction (about 80 %) of BOD for all the three filter combinations put in use in the study. Coliform test indicated that inflow water contained coliform bacteria beyond permissible levels. After the filtration, there were no trace of coliform bacteria and this outcome is worth highlighting.

Estimation of filtration efficiency of the suspended matter gave values of 81.3 for the solitary micro mesh filter and 85.0 and 85.5 for the sand and charcoal secondary filters respectively in combinations with the micro mesh filter as primary filter.

Based on the above findings, the following conclusions can be drown out of the study

- pH values of the roof water of RCC and tiled buildings in Tavanur region is very close to 7 and is within the safe limit of drinking water standard.
- EC values showed increase after its interactions with the roofing materials and EC values increases considerably in the case of newer RCC roofs.
- Organic suspended sediment load of roof water, even after first flush is higher than the acceptable limit of potability and hence, rooftop water needs appropriate purification methods to make it potable.

- A 100 micron mesh filter is very efficient in removing the suspended impurities present in roof water.
- Micro mesh filter is also capable of reducing the EC of roof water and in the marginal removal of acidity.
- Micro mesh filter is very easy for the periodic cleaning to remove the filtered out impurities and hence has got the potential to solve the present limitations of the RWH by replacing the presently used sand filter.
- Secondary filters made of sand or charcoal are capable of further reducing the suspended impurities load. They also reduce the EC significantly.
- Micro mesh filter in isolation and the secondary filters in combination with the mesh filter reduces the BOD of the inflow rooftop water by 80-90 %.
- Presence of coliform bacteria was considerable in the roof water inflow and their count reduces to negligible level after filtration by micro mesh and its combination with mesh filter.

Scope for future work

- More indepth study on the performance of existing micro mesh filter may be carried out under natural rainfall conditions and mesh filters finer than 100 μ may be developed and tested
- Suitable automatic first flush system may be developed and evaluated.
- More extensive study on rain water and roof water quality may be conducted for a longer period of time to arrive at more conclusive results on the quality of rain and roof water

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Appendices

Appendix- I

1. Evaluation of water quality of the mesh filter

Sample collection date	Inflow			Outflow		
	pH	Conductivity (µS/cm)	Turbidity (NTU)	pH	Conductivity (µS/cm)	Turbidity (NTU)
20/07/2013	6.2	375	2.8	6.53	335	2.1
30/07/2013	6.2	136	2.4	6.8	89.5	1.2
20/08/2013	6.05	378	4.4	6.11	257	3.5

Appendix- II

1. Suspended solids of collected samples

1.a. Suspended solids in the inflow water

Sample collected on	Weight of filter paper (mg)	Wt. of filter paper with sample after drying (mg)	Suspended solids in 100 ml (mg)	Concentration of suspended solids (mg/l)
20/07/2013	550	583	33	330
30/07/2013	550	588	38	380
20/08/2013	550	585	35	350
06/09/2013	550	589	39	390
24/10/2013	550	595	45	450

1.b. Suspended solids in the outflow water

Sample collected on	Weight of filter paper (mg)	Wt. of filter paper with sample after drying (mg)	Suspended solids in 100 ml (mg)	Concentration of suspended solids (mg/l)
20/07/2013	550	555	5	50
30/07/2013	550	557	7	70
20/08/2013	550	556.5	6.5	65
06/09/2013	550	558.32	8.32	83.2
24/10/2013	550	558.5	8.5	85

Appendix- III

1. pH of the selected samples

Concentrations with different roofing materials	Inflow	Mesh filter	Mesh with Charcoal filter	Mesh with Sand filter
0.45 g/l				
Clay tile	5.61	6.31	6.25	6.26
Concrete	5.91	6.01	6.15	6.11
Asbestos	5.65	6.05	6.13	6.25
0.67 g/l				
Clay tile	5.77	6.31	6.43	6.16
Concrete	5.84	6.41	5.94	6.06
Asbestos	5.71	6.36	6.48	6.21
0.89 g/l				
Clay tile	5.01	5.71	6.08	5.84
Concrete	5.02	5.84	6.16	5.85
Asbestos	5.41	5.83	5.89	5.77

Appendix- IV

1. Electrical conductivity of samples in µS/cm

Concentrations with different roofing materials	Inflow	Mesh filter	Mesh with Charcoal filter	Mesh with Sand filter
0.45 g/l				
Clay tile	279	134	82.2	92.5
Concrete	290	61.1	92.6	73.5
Asbestos	234	69.0	98.5	78.5
0.67 g/l				
Clay tile	380	67.8	75.2	79.9
Concrete	460	74.2	76.7	100
Asbestos	250	95.3	81.4	78.2
0.89 g/l				
Clay tile	282	79.2	69.4	72.0
Concrete	467	176	89.7	120
Asbestos	276	64.9	75.2	79.2

Appendix- V

1. Turbidity of samples in NTU

Concentrations with different roofing materials	Inflow	Mesh filter	Mesh with Charcoal filter	Mesh with Sand filter
0.45 g/l				
Clay tile	29	3.7	4.3	3.7
Concrete	39	3.2	3.8	4.5
Asbestos	40	3.5	3.2	4.9
0.67 g/l				
Clay tile	31	4.5	3.1	2.9
Concrete	44	2.8	2.6	1.1
Asbestos	45	5.2	3.3	2.1
0.89 g/l				
Clay tile	35	2.5	2.6	5.8
Concrete	58	1.4	3.8	3.7
Asbestos	59	5.9	4.3	1.8

Appendix- VI

1. Suspended solids of samples in mg/l

Concentrations with different roofing materials	Mesh filter	Mesh with Charcoal filter	Mesh with Sand filter
0.45 g/l			
Clay tile	73.0	62.3	75.2
Concrete	65.0	65.4	68.6
Asbestos	70.0	70.1	64.3
0.67 g/l			
Clay tile	72.3	69.3	76.3
Concrete	71.0	73.8	71.6
Asbestos	68.6	65.2	68.5
0.89 g/l			
Clay tile	67.9	73.5	66.4
Concrete	78.6	69.2	74.8
Asbestos	74.4	75.0	76.4

Appendix- VII

1. Determination of BOD in the samples

Concentrations and filter combinations	Dissolved oxygen content in mg/l		BOD of the sample mg/l
	D.O value (D1)	D.O value (D2)	
0.45 g/l (Clay tile)			
Inflow	7.3	4.3	300
Mesh filter	6.8	4.6	44
Mesh with sand	6.5	3.4	62
Mesh with charcoal	6.7	4.4	92
0.89 g/l (Concrete)			
Inflow	6.4	4.7	170
Mesh filter	7.7	4.3	68
Mesh with sand	6.4	3.7	50
Mesh with charcoal	7.2	5.3	76

Abstract

Development of a filter system for roof water harvesting

By

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ABSTRACT OF THE THESIS

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DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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ABSTRACT

Roof top rainwater harvesting has enormous potential in solving the water scarcity of a region, especially the domestic requirement. Roof water needs adequate purification to separate the impurities getting into the rain water from the roof. Conventional filter used for the purpose, a sand and gravel filter, has the inherent limitations of hassle free cleaning and as a result the filter unit go clogged and the entire system become dysfunctional very quickly. To tide over this issue, an M.Tech research work has been taken up with the objective of developing a simple and easy to clean filter system. Under the study, an existing micro mesh filter has been evaluated thoroughly under actual rainfall conditions. Two additional filters viz. sand and charcoal were also developed as secondary filters and connected to the outlet of the mesh filter to improve the purification efficiency. As rainfall was insufficient to test the performance of the sand and charcoal filter combinations with the mesh filter, synthetic roof water was prepared and test was carried out. The study also included testing the roof water quality from different roofs such as clay tiled, RCC paved with terracotta tiles, clay tiled, old RCC and new RCC.

The results showed that pH values of the roof water were not varying with respect to roof materials and their values were very close to 7. EC was varying with respect to roofs and rainfall events but there were no consistency in their variation, also, their values were within the permissible limit of potability. Turbidity and suspended solids were also showing variation with respect to roof and rainfall events, their concentration was higher than the permissible limit. After the filtration, the turbidity and suspended solids concentration reduced by 81% for mesh filter alone and 85% when secondary filter combinations of sand or charcoal were used. All the filter combinations were also capable of reducing the EC values of the roof water significantly. BOD_5 test of the inflow and outflow water also showed considerable reduction in BOD_5 in the outflow water. Coliform test revealed that roof water was

having coliform bacteria, but after the filtration, the presence of coliform bacteria was negligible. The study has proved that the micro mesh filter and the filter combinations with sand and charcoal are very effective in the purification of roof water and they are also very user friendly from the point of view of cleaning.