IMPROVED DESIGN AND INSTALLATION OF AN ECONOMIC ROOFTOP RAINWATER HARVESTING SYSTEM

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **''IMPROVED DESIGN AND INSTALLATION OF AN ECONOMIC ROOFTOP RAINWATER HARVESTING SYSTEM''** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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ABSTRACT

Water resources are depleting at an alarming rate due to its increasing demand. Absolute water scarcity is being experienced in many parts of the country. In such a situation the only solution is to harvest water during rains and preserve it for future use. Rainwater harvesting is a method of capturing rainwater where it falls and taking all precautions to store it unpolluted.

We selected an existing rooftop rain water harvesting system in the KCAET campus and modified its design to make it more economical and efficient. Various polyfilms were compared for their mechanical properties and cost, and finally UVA Clear LDPE of 200 micron thickness was selected as the lining material. A portable shed roof for the storage tank was constructed using GI pipes and UVA Clear LDPE. The existing screen filter was replaced with an upward flow, coir and activated carbon type filter. The density of the filter media was selected by analysing the quality of water and filtration rate at various proportions of the coir fiber and charcoal. The filter media having a density of 83.65 kg/m^3 with a filtration rate of 3.83 $m^3/min/m^2$ and efficiency of 90.2 % was adopted. An automated first flush diversion system was also installed to prevent the entry of first rainwater after a dry season to the filter, so that the excess dirt load is reduced. An underground recharge tank has been constructed to recharge the ground water using the overflow, without losing the land area. The results of physical and chemical analysis of water from various sources and that from the poly lined well showed that, the water collected from the latter was of superior quality compared to other conventional sources. A computer program was developed in Visual basic 6 which gives various outputs for the design and operation of the rain water harvesting system. . From the economic analysis of the project, we found that, for a unit cost of Rs.0.10 per litre of water, Net present worth, Benefit Cost ratio and internal rate of returns were Rs.1,07,484.,four and 86% respectively, which indicates the profitability of the project. It is concluded that designed RRWH system can be strongly recommended for households facing the problems of water scarcity and quality deterioration.

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Symbols and abbreviations

‘	-	Minute
“	-	Seconds
^{0}	-	Degree
cm	-	Centimeter
CGWD	-	Central Ground Water Board
et al	-	and others
Fig	-	Figure
FTA	-	Female threaded adpter
GI	-	Galvanized Iron
h	-	Hour(s)
HDPE	-	High Density Poly Ethylene
i.e	-	that is
KAU	-	Kerala Agricultural University
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
km	-	Kilometers
LDPE	-	Low Density Poly Ethylene
m	-	Meters
m^3	-	Cubic meters
mm	-	Millimeters
min	-	Minute
MTA	-	Male threaded adapter
No.	-	Number
PVC	-	Poly Vinyl Chloride
DRRWH	-	Domestic Rooftop Rain Water harvesting
RWHP	-	Roof Top Water Harvesting Potential
UNDP	-	United Nations Development Programme
USDA	-	United State Department of Agriculture

UVA	-	Ultra Violet Absorption
Vs	-	Versus
viz.	-	Namely

CHAPTER 1

INTRODUCTION

Water is an essential natural resource for sustaining life and environment. The available water resources are under pressure due to increasing demands and the time is not far when water, which we have always thought to be available in abundance and free gift of nature, will become a scarce commodity. Conservation and preservation of water resources is urgently required to be done.

India is blessed with substantial water resources and these resources are regularly replenished by two monsoonal patterns, the SW and NE monsoons. In spite of this, India is water stressed and in the near future is likely to become a water scarce country as a result of varied reasons. Ground water is depleting at an alarming rate due to over withdrawal. Absolute water scarcity is already being experienced in different parts of the country, in high rainfall areas, low rainfall areas, in hilly terrain and in the plains. In such a situation the only solution is to harvest the water during rains and store it for future use.

Due to rapid urbanization coupled with population explosion, the state of Kerala is facing water scarcity and is likely to face water famine if proper management strategy of the resource is not adopted. The state receives 2.78 times more rainfall than the national average and five and three times more than Rajasthan and Tamil Nadu respectively. With about 3000 mm rainfall, chains of back water bodies, reservoirs, tanks, ponds, springs and wells, Kerala is considered as land of water. However, the state of Kerala is frequently facing severe droughts followed by acute drinking water scarcity for the last two decades. Rivers hardly contain any water during six months of a year; only few reservoirs get filled up even during the monsoon. In summer, water level goes down to the silted up bottom in many cases. Continued exploitation of ground water resources and utter ignorance on their susceptibility has already caused unimaginable damage and posed a serious threat to the ecological balance. Therefore steps must be taken to maintain hydrological equilibrium between annual replenishable recharge and ground water draft.

Decline of ground water table and increase of population has decreased the per capita water availability in India by four times, where as in Kerala, it has decreased by five times. Even though, Kerala receives 2.78 times more rainfall compared to the national average, unit land of Kerala has to support 3.6 times more population. Hence, for self sufficiency, unit land of Kerala has to produce 3.6 times more food and biomass, also the same unit of land has to provide 3.6 times more drinking water and associated water requirements compared to the national average. More over, because of steep topography of Kerala, more than 90% of the rain falling on the land drains to Arabian Sea within 24 to 48 hours. The steep topography, extreme unevenness of rainfall in time and space, very short river lengths, unique physiographic, geology, soil, vegetation and very high population density has resulted in low capability for conservation of rain water.

The average annual precipitation of Kerala is estimated as 3000mm. However the variation in spatial and temporal distribution pattern causes for frequent floods and droughts in Kerala. About 60% of the annual rainfall is received during SW monsoon (June-August), 25% during NE monsoon (September-November) and remaining during summer months. The State has a surplus of 8506million cubic meters of water in monsoon and a deficit of about 7142million cubic meters in summer. Hence the increasing demand for water to meet drinking, domestic, agricultural and industrial needs in summer is placing greater emphasis on the utilization of surplus during monsoon by proper harvesting and conservation of rain water. Identification of simple, location specific, reliable and environmental friendly technologies of rain water harvesting and the promotion of these technologies is a potential option.

The projected water requirement of Kerala by the year 2021 would be of the order of 48,600Mm^3, with irrigation taking the pride place at 28,900Mm^3(59.5%), domestic and industrial uses 7,500 Mm^3 (15.4%), salinity control 7,200 Mm^3 (14.8%) and improving Kari lands (toxicity removal) 5000Mm^3 (10.3%). Of the total annual requirement of 48,600Mm^3 about 70-75% will be needed during the summer months, while the summer flows will only be about 15%. The requirements during summer season will be of the order of 35,000Mm^3; the availability will only be about 10,000Mm^3, of which only about 6000Mm^3 will be utilizable. It is to be stressed here that the State has to develop a definite plan to augment the surface and ground water storage and to utilize water more efficiently.

For centuries, world has relied upon rainwater harvesting to supply water. Rainwater harvesting promotes self sufficiency and fosters an appreciation for water as a resource. It saves money, saves other resources of water, reduces erosion and storm water runoff and increases water quality. Rainwater can provide clean, safe and reliable water for drinking so long as the collection system is properly constructed and maintained and treated appropriately for its intended use. Rainwater harvesting means capturing rain where it falls or capturing the runoff in a village or town and taking all precautions to keep it unpolluted. One third of world's population is experiencing severe water scarcity right now. In rural areas, the water may not be fit for drinking due to the polluted water bodies, due to contaminated ground water and also due to acute water scarcity. In urban areas, water demand increases due to increase in the population. Hence, the most effective way to obtain fresh drinking water is to harvest rainwater. Rainwater harvesting system is inherently simple in form, and can often be assembled with readily available materials by owners, builders with a basic understanding of the plumbing and construction skills. We propose our project with a vision to overcome the scarcity of drinking water during the non – rainy seasons such that it gives easy and economical solution that can be adopted both in urban and rural areas.

The aim of this project was to collect and store the roof water in polythene lined tanks. Water from the roof is collected in gutter and conveyed to the storage tank through down pipe and filter. Designing of this system includes the selection of suitable lining material, designing of filter, recharge pit, first flush valve and roofing. We selected one of the existing roof water harvesting system and redesigned its components for making it more economical and acceptable for the house hold purpose. The major objectives are the following

1. To select a suitable lining material to replace the existing one.
2. To design a filter with improved filtration rate and efficiency.
3. To design a strong and aesthetic portable roof.

4. To design an underground recharge pit for the effective utilization of overflow from the storage tank.
5. To design an automated first flush diversion system to divert the water collected from the first rain.
6. To develop a user friendly computer program for the design of RRWH and its associated water collection, storage and recharge computations.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Rain water harvesting

Water is essential for all life and used in many different ways. It is also a part of the larger ecosystem in which the reproduction of the biodiversity depends. Fresh water scarcity is not limited to the arid climate regions only, but in areas with good supply the access of safe water is becoming critical problem. Lack of water is caused by low water storage capacity, low infiltration, larger inter annual and annual fluctuations of precipitation and high evaporation demand.

The term water harvesting was probably used first by Geddes of the University of Sydney. He defined as the collection and storage of any form of water either runoff or creek flow for irrigation use. Meyer’s of USDA, USA has defined it as the practice of collecting water from an area treated to increase runoff from rainfall. Recently Currier, USA has defined it as the process of collecting natural precipitation from prepared watershed for beneficial use. Now a days water harvesting has become a general term for collecting and storing runoff water or creek flow, resulting from rain in soil profile and reservoirs both over surface and under surface. Previously this was used for arid and semi arid areas, but recently their use has been extended to sub humid and humid regions too. In India water harvesting means utilizing the erratic monsoon rain for raising good crops in dry tracks and conserve the excess runoff water for drinking and for recharging purposes.

The basic principle of rainwater harvesting is to ‘Catch the water where it falls’. It involves collection, storage and recycling of rainwater for domestic, agricultural or industrial purposes. Rainwater harvesting does not imply the harvesting of water received directly from rains only, but also from all other natural resources like rivers, streams, lakes, ponds, wells, water springs, ground water aquifers etc. Since all such resources draw water from the rain (and snow fall) itself. The rain water harvesting is mainly done for the following purposes.

1. For direct use.
2. For augmenting groundwater storage.

2.1.1 Rain water harvesting for direct use

Rainwater harvesting for direct use is done by collecting and storing rain water from roof tops, land surface or rock catchments.

2.1.1.1 Rainwater Harvesting from Rooftop Catchments

In most basic form, it is the collection and storage of rain water from roof top of buildings and utilization during summer season. Rooftop rain water harvesting can be used either for storage in tanks for domestic use or for recharging the ground water or for both. 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 fact that all the rain water falling over an area cannot be effectively harvested. The runoff coefficients vary from 0.7 to 0.9 with the type of roofing materials.

The storage capacity needed should be determined taking into consideration the size and type of catchments, the cost of the system and its reliability for assured water supply. Thus,

$$\text{Capacity, } Q = (n \times q \times t) + e$$

Where,

n is the number of persons in the family

q is the consumption, litre per capita per day

t is the Number of days or dry period for which water is needed

e is evaporation losses from the tank (negligible if the tank is covered at the top)

The excess water from the catchment can be diverted to a recharge pit which will help to raise the level of ground water table. The rain falling on the catchments are conveyed to the storage system by gutters and pipes. Gutter collects the rain water runoff from the roof and conveys the water to the down pipe. Gutters with semicircular cross section can be made by cutting large diameter PVC pipes. They are laid on a mild slope (0.5%) to avoid the formation of stagnant pools of water. The size of the gutter should be according to the flow during the highest intensity rain. A semicircular section of 150 mm diameter is enough to carry away most of the intense rainfall. A vertical down pipe of 75-100 mm diameter may be required (depending on the roof area) to convey the harvested rain water to the well. An inlet screen (wire mesh) may be fitted at the inlet of the down pipe to prevent the entry of dry leaves and other debris into the pipe.

The first flush of water from the roof is likely to contain dirt, droppings and debris collected on the roof. This contaminated water should be diverted from the storage tank to avoid polluting the stored rain water. Hence a first flush diversion system or a bypass line should be provided in the down pipe to dispose the water from the first few rains. In order to drain this polluted water, a pipe and valve assembly is fixed with a Tee joint to the down pipe. After the first rain is washed out through this, the valve is closed to allow the water to enter the down pipe and reach the well. The excess water and the water from the first few rainfalls can be utilized for recharging groundwater by various methods.

The dirt and debris if any in the water coming through the down pipe are to be removed before entering the storage well for which a filter unit is provided over the storage well. This unit is a container or a chamber filled with filter media such as coarse sand, charcoal, coconut fiber, pebbles and gravels. A plastic or aluminium bucket or a chamber made of ferrocement can be used as filter unit. The container is provided with perforated bottom to allow the passage of filtered water to the well. The filter media is arranged from top to bottom in the chamber as below:

Table 2.1 Arrangement of filter media

Layer	Material	Thickness (mm)
1	Gravel of 20 mm size	50
2	Charcoal	50
3	Coarse sand	50
4	Coconut fiber	50
5	Pebbles of 10mm size	10
6	Gravel of 20 mm size	50

Studies have shown that the water, which has purified through this filter and kept closed from sunlight, will remain safe for a period of up to 6 months. To maintain the purity of water, the filter bed must be washed or changed once in a year. A man hole should be provided at the top of the well for manual cleaning and that should be covered in order to prevent the entry of insects, dusts and other foreign materials. Among the various techniques of water harvesting, harvesting water from rooftops need special attention because of the following advantages involved in the method.

1. The roof catchment area is relatively clearer and free from contamination compared to ground level catchments.
2. Losses from roof catchments are minimum due to small size and type of material of roof.
3. This is an ideal solution of water problem where there is inadequate ground water supply or surface resources are lacking.
4. It helps to reduce flood hazard.
5. The structures required for harvesting rainwater are simple economic and eco-friendly.

Gogte (2001) studied the rural rainwater harvesting practices in Israel. Israeli scientists have received a boost in agriculture production in the Negev desert using water-harvesting practices.

Preman (2001) studied about the revival of traditional water harvesting systems in Kerala. Kerala is now involving communities in water harvesting and conservation through projects such as the 'Akaashaganga' in Kozhikode district.

Ranjan (2001) conducted a study about rain water harvesting in Indo Gangetic plains of Dihra village in Bihar. Here the traditional pyne and Anars have been utilized to meet irrigation demands at times, when the zonal canal failed to meet the purpose.

2.1.1.1.1Components of RRWH system

The roof of the house is used as the catchment for collecting the rain water. The style of construction (flat or sloped) and material of the roof affect the stability as a catchment. Roof is made of corrugated iron sheet, asbestos sheet, tile, slates or concrete can be utilized as such for harvesting rain water.

i. Gutter

Gutter collects the rain water runoff from the roof and conveys the water to down pipe. Gutter may be constructed in semicircular or rectangular shape. Semicircular gutters (15 cm to 25 cm) of plane galvanized iron sheets are commonly used. All gutters should have a mild slope of 0.5%. Half cut PVC pipes of suitable diameter can also be adopted.

ii. Down pipe

A vertical down pipe of 75 mm to 100 mm diameters may be required, to convey the harvested rainwater to the storage tank. PVC or GI pipes are commonly used as down pipe.

iii. First flush pipe or foul flush diversion

The first flush of water from the roof is likely to contain dust, droppings and debris. Thus contaminated water should be diverted from the storage tank to avoid polluting the stored rainwater. Such a diversion can be achieved by including a ninety-degree elbow on the down pipe so that the pipe can be turned away from the storage tank to divert the flow for the first 5 to 10 minutes of a storm.

iv. Storage tank

Storage tank is used to store the water that is collected from the rooftops. For storing larger quantities for water the system will usually require a bigger tank with sufficient strength. For domestic water needs, taking the economy and durability of tanks into consideration, ferro cement tank of cylindrical shape is used.

The decision, whether to store or recharge rain water depends on the rainfall pattern of a particular region. In areas, where the total annual rainfall occurs only during one to two months, the water collected during the monsoon has to be stored throughout the year, which requires large volume of storage containers as well as some treatment processes. Therefore, ground water recharge is more feasible, that is, to use rain water to recharge ground water aquifers so as to draw water during the rest of the year. Therefore, ground water recharge is more feasible, that is, to use rain water to recharge ground water aquifers so as to draw water during the rest of the year, rather than storing in large containers which is not always feasible.

Gera (1996) has reported that RRWH system was developed at Nagarcoil, which was situated about 80 km from Thiruvananthapuram towards Kanyakumari. A 5 m^3 ferro cement tank was used which provides drinking water to a family for 200 days.

Dunglena (2001) reported that Aizawal in Mizoram had more than 10000 rain water harvesting tanks in individual homes, which had been constructed by the residents at their own expense. Rooftop rain water harvesting was widely practiced there. The quality of the rain water collected was relatively good since the sources of pollution are few. The Government of Mizoram has a policy to replace all thatched roofs with GI sheet roofs. This is being done to improve village homes and to promote rooftop water harvesting.

Jayakumar (2001) reported that rooftop rainwater harvesting system was a practicable option to drinking water problem in Chennai. Rainwater pits constructed helped to augment the ground water to the maximum by dispersing in the plot, which will in turn charge the wells present in the plot by underground water movement. As the water came through the roof was collected in a proposed storage well and the same could be diverted in to the existing service sump. To handle the excess outflow, percolation bore pits were provided.

Kulkarni (2001) reported that rooftop harvesting has been traditionally practiced in Maharashtra in times of need. The UNICEF has recently extended support to build RRWH system that has proved to be quite popular.

Mehta (2001) reported that water-harvesting structures built by villagers in Kunda taluk, Amreli district, Gujarat had changed the ecology and economy of the region. The increased water availability has also increased the agricultural income by Rs.7.35 crore. It had also created 3.5 m^3 of water storage capacity at cost of 1 Rupee per 160 litres, which led to an increase of 5 to 15 m in the water table in wells in surrounding areas.

With a view of promoting rooftop rain water harvesting, the Ministry of Water Resources (2001) has proposed to the Ministry of Urban Development to consider enactment of suitable legislation for provision of rooftop water harvesting for buildings at NCT and other cities by the concerned organizations.

Titala *et al*. (2001) studied on economic impact of water harvesting structures. The structures were made in Raj Samadhiyala of the North-Saurashtra Agro-Climatic zone. The impact of water harvesting structures on cropping pattern of farmers, crop yields and income of farmers, inequality between incomes of beneficiaries was evaluated.

Athavale (2002) reported that rooftop rainwater harvesting and storage or artificial recharge through a filter pit adjacent to hand pumps in a school building, Panchayath office etc. is one of the current methods of de-arsenification. In the early 1980s, cases of arsenic dermatitis were reported from some districts of West Bengal.

Hameed *et al*. (2002) studied about the importance of rooftop rainwater harvesting techniques in supplementing fresh water for domestic purpose in Lakshadweep islands where the limitation of fresh water is a major problem. This is due to the peculiar hydrological and demographic features of the island. The fresh water demand of the islands cannot be met from the available ground water. Additional withdrawal of ground water may lead to upward diffusion of saline water. Hence, the only feasible solution to meet the drinking water requirement of the island is rooftop rain water harvesting technique.

v. Lining Material

To check the seepage losses of stored rain water, the pond must be lined with suitable sealants, the choice of which depends upon the texture of the soil, availability of lining material, durability and cost. Soil cement, cement concrete, brick or stone, chemical additives and different types of geo membranes can be used as lining materials. HMHDPE film, hot mixed asphaltic concrete, glass fibre, asbestos felt, asbestos fibre etc. are used for this purpose. However, LDPE black polyethylene sheet and UV–resistant blue silpolin sheet were found best lining materials. Poly sheets are generally available in widths of 1.8 to 14 metres. The sheets of required widths should be procured to avoid jointing. If needed, the poly sheet pieces can be joined together by heat sealing. Before laying the sheets, the walls of the structure must be smoothened by removing any protruding objects like pebbles, roots etc. and a thin layer of mud is pasted between the sheet and the walls of the structure to avoid puncturing of the structure. The sheet must be protected from sunlight by providing suitable roofs.

The Bureau of Reclamation (1968) has installed over 4,000,000 m^2 of geo membrane canal liner. Reclamation continues to evaluate the performance of new materials in new applications for canal lining. Recent installations in South Dakota, Washington, Nebraska and Oklahoma contain relatively new materials installed as either exposed or covered canal liners. Results shows that geo membranes used as canal liners appear to reduce seepage in the canals when they are constructed in highly permeable or collapsible types of soils.

Kraatz (1977) summarized the estimated water losses in lined and unlined conveyance systems from different countries of the world.

Dwivedi *et al*. (1983) conducted a field experiment to determine seepage losses in five different lined ponds and an unlined pond. The results of the experiment showed that the amount of water lost in m^3/m^2 per annum were 4.30, 18.32, 12.20, 22.91, 28.93 and 75.96 from ponds lined with cement mortar (1:6) plastering over lime fly ash soil base, brick lining with cement pointing, polyethylene membrane, lime-fly ash-soil with cement slurry coating, hot applied asphalt lining and an unlined ponds respectively.

Wilkinson (1985) examined the performance of plastic lining on Riverton unit of Wyoming. The average magnitude of seepage losses from the different stations were found to be 0.0018 m^3/m^2/day for plastic membrane lining of 0.25 mm thickness and 0.0013 m^3/m^2/day for that of 0.51 mm thickness.

David (1986) had conducted a quality assurance program for polyethylene lining and discussed appropriate procedures for all phases of the program, beginning with the basic raw material and continuing through a completed field installation. Raw materials and manufacturing quality assurance are described in detail for the three manufacturing processes by which polyethylene resins are processed for liners. They concluded with suggestions for a specifier or end-user in appropriate record-keeping of quality assurance documentation.

Pandya *et al*. (1986) worked out the average conveyance losses in lined and unlined channels. The calculated water loss from the lined channel was 4.96 per cent of the initial discharge, whereas it was 28.31 per cent for the unlined channel.

Taley *et al*. (1986) in their study on the performances of different irrigation channel lining materials observed the losses due to seepage were varying from 0.3861 m^3/m^2/day from unlined earthen channel followed by brick lining with 0.1472 m^3/m^2/day and seepage from soil stabilized mortar faced tiles was 0.1214 m^3/m^2/day. The least seepage was obtained from polyethylene lined channel which was 0.0432 m^3/m^2/day.

Tiwari *et al.* (1990) studied the performance of evaluating of lining materials for seepage control from farm ponds. Six farm ponds of 100 m^3 capacity were constructed and their seepage rates were observed during monsoon and post monsoon periods. During monsoons, the water table was observed to be close to the pond bottom which restricted the vertical flow of water. Pond lined with low density polythene film gave the lowest seepage rate, compared with ponted brick lining and cement soil lining materials.

He also observed the performances of different lining materials on farm ponds. The average seepage rates from the different materials studied were found to be 6.7, 2.5, 4.8, 19.6, 17.4 and 27.1 cm/day respectively for ponds lined with 150, 200 and 250 micron plastic films; cement mortar pointed bricks, soil-cement and for the unlined one.

The steady state seepage rates observed from six experimental field channels; five lined with cement pointed brick lining, low density polyethylene (LDPE) overlain with 15 cm soil cover, cement pointed brick underlain with LDPE, LPDE sheet overlaid on side with cement pointed bricks and with 15 cm soil cover on the bottom and the 6^{th} unlined channel were 1.350, 0.057, 0.121, 0.011, 0.310 and 3.228 $cm^3/cm^2/h$ respectively.

Ahmad *et al.* (1993) conducted studies on the performance of various lining materials. The paper discusses the performance of various lining materials to reduce such losses. Brick lining has many site specific field problems. Soil sealants/emulsions need a lot of improvements in their sealing properties under varied local conditions. Polythene sheets are damaged by weed growth and animal damage. Synthetic rubber membranes under protective covers, gave fairly good results, except for some problems with bonding.

Siddique *et al.* (1993) described that the analysis of seepage data collected on Chashma right bank canal, Pakistan, during the period of 1990-92 gave an average seepage rate of 4.381 $\pm$ 344 Cfs/mfs, with 95 per cent confidence interval, for earthen reaches and 2.971 $\pm$ 0.306 Cfs/mfs for lined reaches. They reported the expected total seepage losses from the project area to be 385 Cfs and 327 Cfs from the unlined and lined reaches respectively.

vi. Filter unit

The filter unit is a container or chamber filled with filter media such as coarse sand, charcoal, coconut fibers, pebbles and gravel to remove the debris and dirt from water that enters the tank. This container is provided with a perforated bottom to allow the passage of water.

Bruce *et al*. (1992) described in their article that treatment systems for household water supplies with activated carbon filtration is the most effective in removing organic contaminants from water. Because organic chemicals are often responsible for taste, odour and colour problems, they concluded that AC filtration can generally be used to improve aesthetically objectionable water.

Harris *et al*. (2000) concluded that the sand filtration reduces the bacterial content as well as colloidal content. They also reported that properly installed and maintained system for treating and disposing of household water will minimize the impact of that system on ground water and surface water.

Elizabeth *et al.* (2001) described sand filters for water treatment.

Campos *et al.* (2002) described in their article " Biomass development in slow sand filters" that microbial biomass development in the sand and biofilm layer was determined in two full- scale slow and filters, operated with and without a light excluding cover.

Mary *et al.* (2003) reported that the sand filtration was proved to be highly effective in small scale platforms.

2.1.2 Rain water harvesting for augmenting ground water storage

Ground water recharge can take place naturally and by manmade constructions or modifications. The recharge take place in a natural condition through infiltration and rainfall are the most important source of natural groundwater recharge. Any process by which man fosters the transfer of surface water into the groundwater system can be considered as artificial ground water recharge. The choice of method depends on local topography, hydro-geological characteristics of aquifers, soil condition and quantity to be recharged and ultimate water use. Artificial recharge projects serve water conservation, water management, overcome problems due to overdraft, control sea water intrusion etc.

A variety of methods are used to recharge the groundwater artificially, namely, water spreading methods like flooding, percolation tanks, check dams, ditch and furrow systems etc.

2.1.2.1 Recharge pit

Recharge through pits is practiced in areas where sub-strata restrict the downward passage of water and where aquifer is situated at a moderate depth. Pits penetrating such layers can supply water directly to underlying materials with higher infiltration rates. These pits may be one to two metre diameter or wide and two to three metre deep and back-fill with boulders, gravels and coarse sand. In non-water logged areas, rain pits can be made at various locations and around wells, which will enhance the percolation of rainwater and increase the level of water table. Pits are also used for groundwater recharging through rain water harvest from roof tops. The dimension of the pit depends upon texture of soil, topography and amount of rainfall received.

Chattopadhyay (2001) reported that paddy fields and low lands had served as traditional water harvesting system since ages. Except in the Kuttanad region, narrow valleys receive sediment and water from the surrounding slopes. The loose sediments retained water and helped in ground water recharge. Studies around the Sasthamcotta lake indicated the importance of preserving these fields and low lands for recharging the lake.

Foel *et al*. (2001) designed a major artificial recharge scheme to augment the aquifers supplying the domestic and industrial requirements in the Mount Newman mine and in Western Australia. The scheme involved detention of surface flood waters by a major dam and after a period of setting of silt loads, water is directed to the recharge basin.

Gane *et al*. (2001) conducted study on ground water recharge estimate of a small watershed. The total annual recharge was calculated as the sum of total monsoon recharge, non monsoon recharge and from surface sources of irrigation and potential recharges. The net utilizable recharge is taken as 85% of gross recharge.

Pundarikandan (2001) reported that high and moderate recharge zones were areas suitable for the artificial recharge activity. In the other zones low cost small recharge structure might be contemplated according to the local need. Percolation ponds were also recommended in favourable recharge zones.

Ambily *et al*. (2002) conducted a study on the evaluation of aquifer parameters from pumping test data in KCAET Tavanur. The specific yield of lateritic formation was found to be 0.00134. The hydraulic conductivity of laterite was estimated to be 3.7×10^{-5} m/s.

Athavale (2002) reported that the artificial recharge project undertaken by CGWB in central region of Nagpur has demonstrated the feasibility of utilizing sample structures like percolation tanks, check dams, recharge dug wells and recharge shafts. Efficiency of the tanks constructed varied from 78% to 91% for the Amaravay district. He also reported that the CGWB with the assistance of UNDP has undertaken artificial recharge studies involving induced recharge and recharge through injection wells at two sites in Haryana. A project on augmenting the depleted aquifers in the Mehsena area was conducted by the CGWB. They simultaneously undertook a project on artificial recharge for controlling the saline intrusion in the coastal belts of Gujarat. In Mehsena area artificial recharge experiments through the spreading method were conducted using canal water. The recorded buildup in water level of 3.5 to 5 m was observed up to 15 m from the recharge channel and about 20 cm at a distance of 200 m. Another experiment using recharge pit, 1.7 X 1.7 X 0.75 m to study the feasibility of recharging the shallow aquifers was conducted at Dabhu in central Mehsena area. A rise of 4.13 m in water level was observed at a distance of five metre from the recharge pit.

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

Bineesh *et al*. (2004) conducted a study on the estimation of ground water recharge in KCAET campus, Tavanur, Malappuram. They estimated the specific yield of lateritic formation to be between 0.07 to 0.13 m for different sites within the campus.

Kavitha *et al*. (2005) conducted a study on recharge and discharge studies in laterite soils in KCAET Tavanur, Malappuram. The study showed that artificial recharge had a great impact on ground water table rise of open wells.

2.2 Quality of harvested water

In India about 21% of all communicable diseases (11.5% of all diseases) are water borne in nature. According to an estimate, 73 million working person days are lost every year owing to be people falling ill due to water borne diseases. Diarrhea, which is the most prevalent water borne disease, is responsible for 25-30% of deaths among children below the age of five years. Also, epidemics of infectious hepatitis, food poisoning and typhoid are quite common. India incurs an expenditure of about Rs. 36,600/- crores per year on treatment of water related diseases. To prevent the incidence of water borne diseases, there is a need to improve the quality of drinking water.

Rainwater collection systems are commonly believed to provide safe drinking water without treatment because the collection surfaces (roof) are isolated from many of the usual sources of contamination (e.g. sanitation systems). Although the roofs are at a higher elevation than the ground, dust and other debris can be blown on to them, leaves can fall from trees, and birds and climbing animals can defecate upon them. The quality of drinking water can be much improved if these debris is not allowed to enter the storage well. The more do we keep a roof clean, the better the water quality will be.

With the term “quality” seems ambiguous; its frequent use would suggest a widely accepted meaning. The concept of water quality standards was introduced into Pollution Control Legislation with the passage of water quality act of 1965. In 1997 the chemical water standards were established by the environmental protection agency, which is recommended by the World Health Organization.

Puttaswamaia (2002) said that inadequate resource management and institutional system seems to be major causes for poor water quality problem. Operation and maintenance of drinking water quality scheme, water quality monitoring and ground water conservation and rain water harvesting measures have to be implemented for better provision of drinking water supply.

Bineesh *et al*. (2004) conducted studies on salient features of ground water resources and quality of drinking water in the KCAET campus. They found that drinking water contains high coliform content and low pH. The rest of drinking water quality parameters remain in the tolerable limits.

According to Jenson (2004) apart from hazards of high pollution levels, sustainability criteria has to be included in the water quality guidelines to account for long term low level application of pollutants.

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

In a study conducted by Narasinhaprasad (2005) total hardness and salinity were found to be critical water quality parameters, according to the permissible levels of drinking water standards.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

Study has been conducted on the existing large capacity roof water storage system constructed by Akarsh *et al.* (2009) near the smithy shop in the K.C.A.E.T campus, Tavanur, Malappuram district. It is situated at 10°52’30” north latitude and 76° east longitude.

3.1.1 Existing System

3.1.1.1 Catchment area

The roof of the smithy shop was selected as the catchment area for rainwater harvesting. The plan area of the roof of smithy shop building of K.C.A.E.T, Tavanur is 140 m^2. But only half of the area is used for the rain water harvesting, so the net effective area is 70 m^2.

3.1.1.2 Gutter and Conveyance System

Gutter with semi circular cross-section of diameter 150 mm made of PVC material was laid along the roof of 17.5 m length with a slope of 0.4% for collecting the rain water. To safely convey the harvested rain water to the storage tank, a vertical down pipe of 63 mm diameter was connected to the gutter.

3.1.1.3 Filter System

The filter of the existing system was an upward flow type, which was constructed using two PVC pipes of diameter 110 mm and 63 mm and screen having mesh size 600 micron. The overall height was 40 cm, providing a screen area of 0.079 m^2. The flow rate of the filter was 1.104 $m^3/min/m^2$.

3.1.1.4 Polylined Storage Tank

The storage tank was constructed by digging a square pit of size $3 \times 3 \times 2$ m and constructing the laterite stone masonry above the hardpan upto a height of about 1 m above the ground level. Thus, the estimated capacity of the storage structure is 27 m^3. To check the seepage losses of the stored rain water, the structure was lined with an LDPE black polythene sheet of 300 micron thickness.

3.2 Climate

Agro climatically the area falls within the boarder line of northern zone, central zone and kole zone. The area selected is having an average annual rainfall of about 3000 mm. The area receives the rainfall mainly from south-west monsoon and north-east monsoon.

3.3 Experimental Details

3.3.1 Selection of lining material

By considering the soil type, puncture resistance, tensile strength, durability, chemical reactivity, microbial resistance, availability and cost of various poly films, a suitable poly film of required thickness has been selected.

3.3.2 Design of storage tank roof

The existing storage tank was protected with a temporary roof constructed with Bamboo piles and Silpaulin sheet. A strong, permanent roof is necessary to protect the stored water from the entry of dust, debris, droppings, insects and their excreta. Shed roof (one side slanting) design has been selected to make it economical. To reduce the risk of corrosion, GI pipe of ¾" diameter has been selected for the frame construction. UV stabilised LDPE sheet of 200 micron has been selected as the roof material. The sheet is held tight to the frame using a set of Aluminium channel and zig-zag spring arrangement.

3.3.2.1 Length of GI pipe required

Considering x% slope for the roof, angle of inclination

$$\theta = \tan^{-1}\left(\frac{x}{100}\right)$$

$$\text{Length of pipe required} = a\,[5+2\tan\theta + (2+n)\sec\theta\,]$$

Where,

a is the side of square pit, m

n is the number of inclined supports.

3.3.2.2 Area of sheet required

The area of sheet required for covering the roof can be determined by the following equation

$$A = a\,(6\tan\theta + 3\sec\theta)$$

Where,

A is the area of sheet required, m^2

a is the side of square pit, m

3.3.3 Design of filter unit

The dirt and debris if any, in the water coming through the down pipe are to be removed before entering the storage tank for which a filter unit is provided. An upward flow filter is selected as it has an advantage that it provides an initial settlement with which filtering efficiency can be improved. Combination of coir and charcoal has been selected as the filter media.

The filtration rate and quality of water varies with the density (or porosity) of the filter media. The quality of water is tested by varying the density of filter media as per procedure under 3.4.1.2.1. Among the trials a suitable design with appreciable filtration rate and water quality has been selected to achieve the maximum possible discharge.

3.3.3.1 Design for maximum discharge

The density of the filter media is adjusted in such a way, to permit the maximum discharge through the conveying system without any loss.

As a trial, the filter media is filled at any density. The coefficient of permeability, k_1 for the same set up is found out as per the procedure under section 3.3.3.1.1. Dry density ρ_{d1}, porosity (n_1) and voids ratio (e_1) for the filter media are also found out as per procedure mentioned under 3.3.3.1.2.

The value of coefficient of permeability for the maximum discharge, (k_2) can be found out from Darcy's equation.

$$k_2 = \frac{Q_m \times L}{h \times A}$$

Where,

k_2 is coefficient of permeability for the maximum discharge, m/min

Q_m is the maximum discharge, m^3/min.

L is the height of filter media

h is the head of water

A is the cross-sectional area of filter media

Density of the filter media required for maximum discharge can be calculated by the following relation

$$\rho_{d2} = \frac{\rho_{d1}(1 + e_1)}{(1 + e_2)}$$

e_2 can be calculated by the equation

$$\frac{k_1}{k_2} = \frac{e_1^3 \times (1 + e_2)}{(1 + e_1) \times e_2^3}$$

Where,

k_1 is coefficient of permeability of the filter media in trial set up, m/min.

e_1 is void ratio for the filter media in trial set up.

ρ_{d1} is dry density of the filter media in trial set up, kg/m^3

k_2, e_2, ρ_{d2} are the corresponding values of the filter media for the maximum discharge.

3.3.3.1.1 Coefficient of permeability for trial filter set up

Coefficient of permeability for the trial filter set up (k_1) is found out by conducting constant head test in the set up at itself, by maintaining constant head and water in the gutter.

3.3.3.1.2 Dry density, Porosity and Voids ratio of trial filter set up

A known mass of filter media (M_d) is filled into the filter pipe. Water is taken in a measuring jar and poured into the filter pipe until it is fully filled. Note the volume of water poured.

Dry density, $\rho_d = \frac{M_d}{V}$

Porosity, $n = \frac{V_v}{V}$

Voids ratio $e = \frac{V_v}{V_s}$

M_d = Mass of filter media filled into the filter pipe, kg

$$V = \frac{\pi D^2 L}{4}$$

Where,

V is the total volume of filter pipe, m^3

D is the diameter of filter pipe, m

L is the length of filter pipe, m

Vv is the volume of voids (volume of water poured into filter), m^3

Vs is the volume of solids,m^3

Vs = V-Vv

3.3.3.2 Filtration rate of filter

Filtered water is collected from the filter outlet for a known time by keeping the head constant. Filtration rate is calculated using the following relation.

$$R_f = \frac{V}{t \times A}$$

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 area of cross section of filter, m^2

3.3.4 Design of Automated first flush diversion system

Debris, dirt, dust and droppings will accumulate on the roof, gutter etc of a building during dry season. When the first rains arrive, this unwanted matter will be washed into the tank. This will cause contamination of the water and the quality will be reduced. Many DRWH (Domestic Rain Water Harvesting) systems therefore incorporate a system for diverting this ‘first flush’ water so that it does not enter the tank.

Assuming seven minutes time for flushing the entire roof area at maximum intensity rainfall, volume of water to be flushed can be calculated by the following equation.

$$V = Q_m \times 7$$

Where,

V is the volume of water to be flushed in 7 min, m^3

Q_m is the maximum inflow rate, m^3/min

A system was designed for the automatic diversion of the design flush volume.

3.3.5 Design of underground recharge system

The dimensions of the recharge pit are determined by the following steps, assuming shape as cubical.

Step 1

Inflow volume = roof area × hourly rain fall depth × runoff coefficient

Step 2

Inflow volume = L^3

L is the width of the cube whose volume is equal to the inflow volume

Step 3

$$\text{Maximum seepage rate} = \frac{\text{Inflow volume}}{\text{Seepage Area}}$$

Step 4

Find out the average seepage rate from minimum seepage rate and maximum seepage rate.

Step 5

$$\text{Area of recharge pit} = \frac{\text{Inflow volume}}{\text{average seepage rate}}$$

Step 6

Find out the dimension of the pit from the area obtained.

3.4 Estimation of water quality

The quality of harvested water is mainly tested to ensure the potability of water. The water has gone through physical and chemical analysis to check whether the quality of harvested water meets the standards specified by WHO.

3.4.1 Physical Analysis

The physical parameters include temperature, pH, colour, turbidity, odour, electrical conductivity and total solids.

3.4.1.1 pH

The acidity or alkalinity of water is expressed as pH. The pH of an aqueous solution is a measure of the acid base equilibrium achieved by various dissolved compounds. The Bureau of Indian Standards recommendation of pH value of drinking water is 6.5 to 8.5. pH is determined by using pH meter.

3.4.1.2 Total solids

The term solid with reference to the environmental engineering is defined as the residue in water left after evaporation and drying. The total solids consist of dissolved and suspended matter.

3.4.1.2.1 Suspended solids

The suspended solids consist of inorganic matter like silt and organic matter like algae. For measuring suspended solids, the water is filtered through a fine filter and the dry material retained on the filter is weighed. The drying is carried out for one hour in an oven at 105^0C.

$$\text{Total suspended solids in mg/l} = \frac{(W_2 - W_1)}{V} \times 1000$$

Where,

W_1 is the initial weight of filter paper, mg

W_2 is the weight of filter paper and the dry material retained on filter, mg

V is the volume of sample, ml

The suspended matter is objectionable in water for the following reasons:

a) It is aesthetically displeasing.

b) It may include disease causing organisms.

c) It may release obnoxious odour.

d) It provides adsorption sites for chemical and biological agents.

3.4.1.2.2 Dissolved solids

In natural water, the dissolved solids mainly consist of inorganic salts like carbonates, bicarbonates, chlorides, sulphates etc. together with small amounts of organic matter and dissolved gases. For measuring the dissolved materials, the water is filtered through a fine filter and the filtrate is then taken in a weighed Petri dish and kept in an oven. The drying is carried out at 105 ^{0}C until complete evaporation of the sample takes place.

$$\text{Total dissolved solids in mg/l} = \frac{(W_2 - W_1)}{V} \times 1000$$

Where,

W1 is the initial weight of filter paper, mg

W2 is the weight of filter paper and the dry material retained, mg

V is the volume of sample, ml

3.4.2 Chemical Analysis

Chemical analysis is done to estimate the hardness and presence of chlorides.

3.4.2.1 Estimation of Hardness

Hardness is the ability of water to cause precipitation of insoluble calcium and magnesium salts of higher fatty acids. The hardness of water is of two types- temporary and permanent hardness.

3.4.2.1.1 Estimation of Total hardness

Total hardness of water is the sum of the concentrations of the metallic cations other than the cations of the alkali metals expressed as the equivalent calcium carbonate concentration. In water hardness is mainly due to the presence of calcium and magnesium.

Reagents:

1. Standard EDTA: It is prepared by dissolving about four gm of disodium ethylene diamine tetra acetate dehydrate in one litre of distilled water and adding 0.86gm of sodium hydroxide.

2. Buffer solution: Dissolve four gm of borax in 100ml of distilled water. Add one gm of sodium hydroxide and one gm sodium or ammonium sulphide.

3. Erichrome Black T indicator.

Procedure

Take 20ml of water sample in a conical flask, add 0.5ml buffer solution and one or two drops Erichrome Black T indicator. Titrate with standard EDTA solution. The end point is the colour change from wine red to blue.

$$\text{Total hardness} = \frac{\text{volume of EDTA}}{20} \times 1000$$

3.4.2.1.2 Estimation of permanent hardness

Permanent hardness is known as non-carbonate hardness and it can not be removed by boiling and it requires special treatment of water softening.

Reagents:

1. Standard EDTA: Dissolve about four gm of disodium ethylene diamine tetra acetate dehydrate in one litre of distilled water and add 0.86gm of sodium hydroxide.

2. Buffer solution: dissolve four gm of borax in 100ml of distilled water. Add one gm of sodium hydroxide and one gm sodium or ammonium sulphide.

3. Erichrome Black T indicator.

Procedure

Boil 20ml of sample for some time. Cool, filter and add 0.5ml buffer solution and one or two drops of Erichrome Black-T indicator. Titrate against EDTA until colour changes from wine red to blue.

$$\text{Permanent hardness} = \frac{\text{volume of EDTA}}{20} \times 1000$$

3.4.2.1.3 Estimation of temporary hardness

Temporary hardness is known as carbonate hardness and can be removed by boiling. After getting the total and permanent hardness the temporary hardness is determined by using the following relation.

Temporary hardness = Total hardness – Permanent hardness

3.4.2.2 Estimation of chloride in water

The presence of chlorine in water is because of the dissolution of salt deposits, discharge of effluents, irrigation, drainage and sea water intrusion. BIS has set a limit of chloride as 250 mg/l in drinking water.

Reagents:

1. Standard silver nitrate solution

2. 5% potassium chromate solution

Procedure:

Pipette 50ml of sample into a conical flask. Add three drops of potassium chromate indicator. Titrate it against standard silver nitrate. End point is the appearance of a pale brown colour.

$$\text{Amount of chloride (ppm)} = \frac{\text{volume of Silver nitrate (ml)}}{50} \times 1000$$

3.5 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 3.4.1.2.1. The efficiency of the filter can be determined by the following equation.

$$E = \frac{S_b - S_a}{S_b} \times 100$$

E = Efficiency of the filter, %

S_b = Suspended solids before filtering, mg/l

S_a = Suspended solids after filtering, mg/l

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Lining material

By comparing the properties of LDPE and HDPE, it is found that LDPE lining has good mechanical and physical properties. Also it has excellent flexibility and cheaper unit cost than HDPE lining materials. Among the different LDPE lining materials available in the market, the UV stabilized sheet possess properties like tensile strength, puncture resistance, tear resistance, durability with pleasing appearance. The UV stabilized sheet also provides certain improved qualities such as anti-microbial and anti-fungal properties.

Among the UV sheets, UVA Clear is selected over others because of its compromising cost and qualities.

Table 4.1 Comparison of different UV stabilized LDPE sheets

Type	Thickness (micron)	Tensile Strength (MPa)	Tear resistance (Gr/mm)	Falling dart drop impact (Gr)	Cost (Rs./m^2)
UVA Clear	200	23.0	8400	1200	48.00
UVA Clear / N	200	23.5	8250	1000	52.00
UVA Diffused	150	22.5	9200	1000	48.00
UVA AV Diffused / N (205N)	150 - 250	23.0	8500	1100	50.00
UVA AV Diffused (205)	150	21.5	8000	1000	47.00
UVA White	150	23.0	8400	900	46.00

4.2 Storage tank roof

A portable shed roof (one side slanting) as shown in fig (4.1) was constructed for the square tank of 3 m long side. GI pipe of ¾" diameter was used for frame construction. It was given a height of 0.75 m at the front, which provides 25% slope for the roof. Two inclined supporting members of 3.1 m length were provided at 1 m interval, with ½" GI pipe, to prevent sagging of roof, two angle iron members were welded at the front at 1 m interval to provide an opening. Aluminium channels were fitted to the GI base pipes on all the four sides. UVA Clear LDPE sheet of 200 micron thickness was tightly fixed on the frame with the help of Aluminium channel and zig-zag spring arrangement. The opening and closing of the door is accomplished by Velcro.

The total length of GI pipe required was 28.86 m and total area of LDPE sheet required was 13.76 m^2.

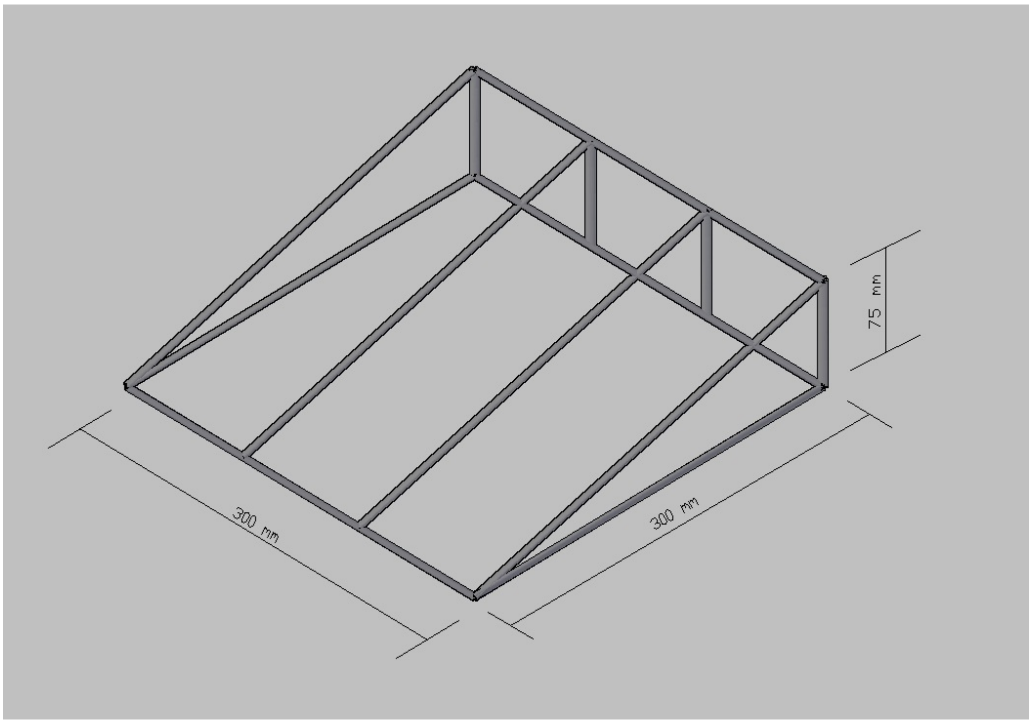

Fig. 4.1 Portable shed roof frame work

Plate 4.1 Shed roof covered with UVA clear sheet

Plate 4.2 Opening for collecting water

4.3 Coir Filter Unit

An upward flow filter was constructed by filling alternate layers of coir fibre and charcoal in a PVC pipe of diameter 110 mm to a height of 80 cm. Charcoal was filled in three layers, each of 3 cm thickness.

The density of the filter media was selected as per the procedure mentioned in 3.3.3 and the observations are shown in tables 4.2 to 4.4. The comparison of the results, table (4.5) showed that, with the density for maximum discharge (81.57 kg/m^3) the filtration rate was 5.05 $m^3/min/m^2$, but the efficiency was only 87.5%. For a higher density of 85.42 kg/m^3 the efficiency was increased to 91.67%, but the filtration rate decreased drastically to 1.05 $m^3/min/m^2$. So we have selected a density of 83.65 kg/m^3, for which the efficiency of filtering and filtration rate were found to be 91.11% and 3.83 $m^3/min/m^2$ respectively.

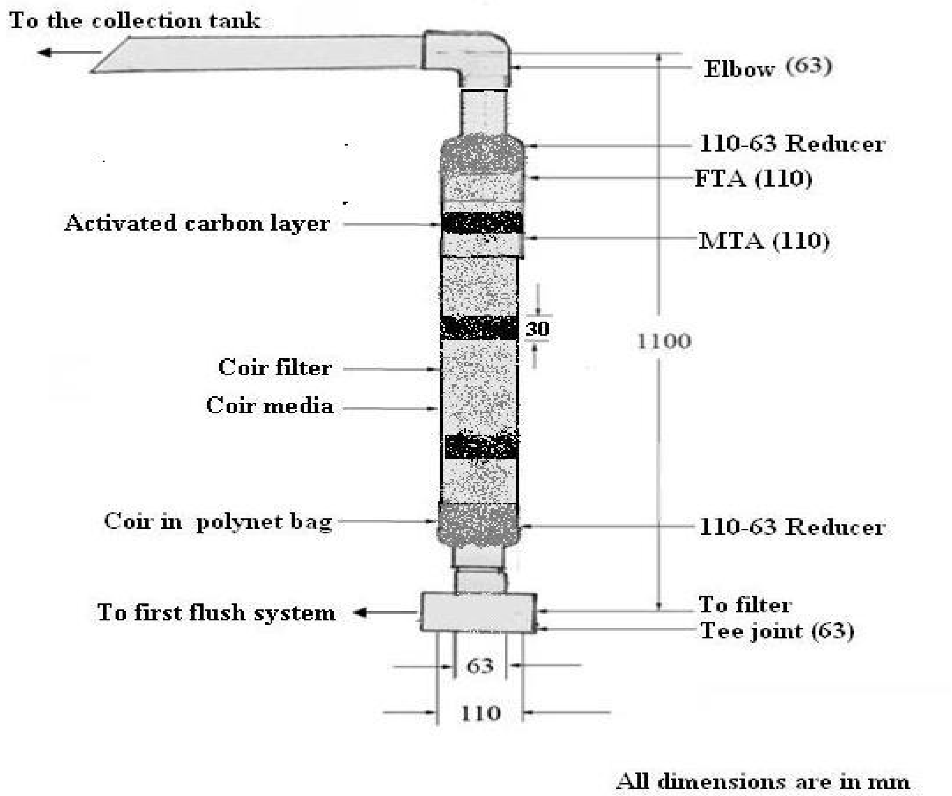

Fig. 4.2 Filter unit

Coefficient of permeability for trial filter set up

Coefficient of permeability for the trial filter set up, k_1 is found out by procedure under section 3.3.3.1.1

Rate of water collected, $q = 1.5 \times 10^{-3}$ m^3/sec

Head of water, h = 2.5 m

Length of filter, L = 0.8 m

Cross-section area of filter pipe = 9.5×10^{-3} m^2

By Darcy's law, k_1 = 0.05 m/sec

= 3.03 m/min

Dry density, Porosity and Voids ratio of trial filter set up

Dry density, Porosity and Voids ratio of trial filter set up is found out by procedure under section 3.3.3.1.2

Dry mass of filter media filled into the filter pipe, M_d = 500 g

Total volume of filter pipe,	$V = 7.6 \times 10^{-3}$ m^3
Volume of voids,	$Vv = 6.6 \times 10^{-3}$ m^3
Volume of solids,	$Vs = 1 \times 10^{-3}$ m^3
So, Dry density,	ρ_{d1} = 65.79 kg/m^3
Porosity,	n_1 = 86.84%
Voids ratio,	e_1 = 6.6

Coefficient of permeability and Density of filter media for the maximum discharge

Coefficient of permeability for the maximum discharge, k_2 and density of filter media, ρ_{d2} for the maximum discharge are found out according to procedure under section 3.3.3.1.

Maximum design discharge, Q_m= 3.136 m^3/hr (Akarsh *et al.*)

So, k_2 = 1.76 m/min

Voids ratio for filter media for maximum discharge, e_2 = 5.13

Dry density of the filter media, ρ_{d2} = 81.57 kg/m^3

Table 4.2 Suspended solids in the inflow water to the filter by varying density of filter material

Density of filter material (kg/m3)	Initial wt. of filter paper (g)	Wt. after drying (g)	Suspended solids (mg/l)
65.79	1.960	2.008	48
81.57	1.767	1.799	32
83.65	1.860	1.905	45
85.42	1.742	1.778	36

Table 4.3 Suspended solids in the filtered water by varying density of filter material

Density of filter material (kg/m^3)	Initial wt. of filter paper (g)	Wt. after drying (g)	Suspended solids (mg/l)
65.79	1.945	1.952	7
81.57	1.823	1.827	4
83.65	1.910	1.915	4
85.42	1.820	1.823	3

Table 4.4 Filtration rates of filters

Density of filter material (kg/m^3)	Water collected (m^3)	Time (min)	Filtration rate ($m^3/min/m^2$)
65.79	0.0045	0.05	9.47
81.57	0.0024	0.05	5.05
83.65	0.00182	0.05	3.83
85.42	0.0005	0.05	1.05

Table 4.5 Comparison of filters of various densities

Density of filter material (kg/m^3)	**Suspended solids before filtering (mg/l)**	**Suspended solids after filtering (mg/l)**	**Efficiency (%)**	**Filtration rate ($m^3/min/m^2$)**
65.79	48	7	85.41	9.47
81.57	32	4	87.50	5.05
83.65	45	4	91.11	3.83
85.42	36	3	91.67	1.05

4.4 Automated first flush diversion system

The down pipe is connected to a Tee-joint on which the filter pipe is fixed. The opposite end of this Tee-joint is connected to a float valve, through a Ball valve. A small flush tank is constructed near this arrangement in such a way that the float gets freely lowered to the flush tank. The size of the pit for the flush tank is $1.2 \times 0.5 \times 0.6$ m and it is lined with LDPE black polythene sheet of 300 micron thickness, to facilitate the storage of 350 litres of water.

The ball valve is kept open in dry seasons, so that when the first rain arrives, the rain water coming from the dirty roof is initially directed to the flush tank. The float rises with the rise in water level of flush tank. Eventually the float valve gets closed, when the flush tank is filled. Thereafter, the rainwater collected will be automatically directed to the main tank, through the filter.

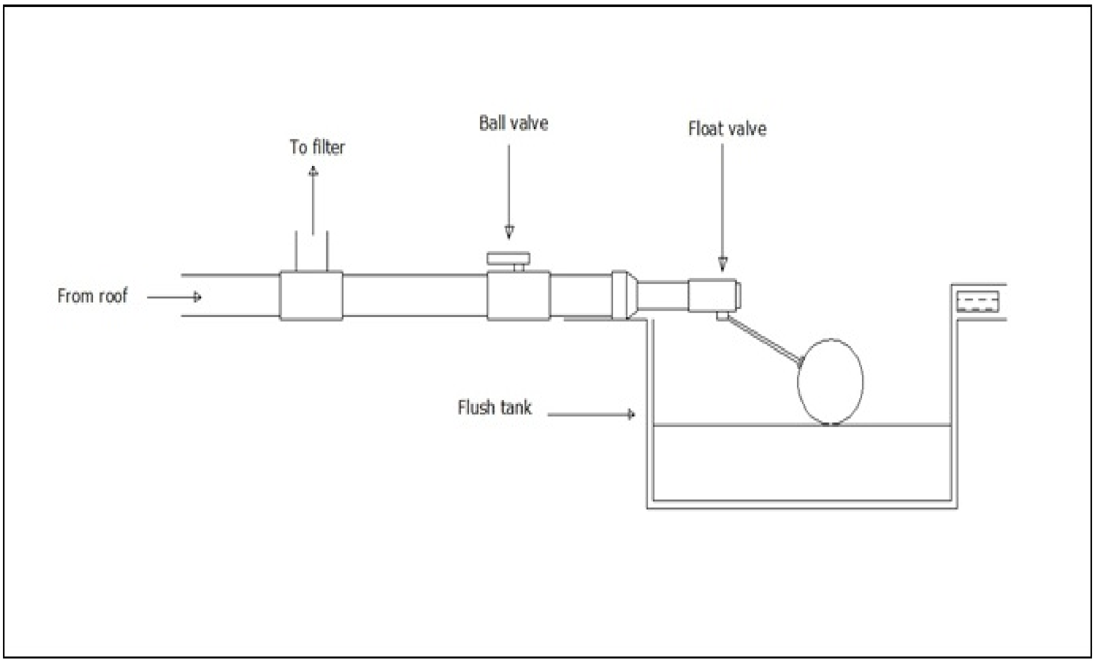

Fig. 4.3 Schematic diagram of first flush diversion system

Plate 4.3 First flush diversion system

4.5 Underground recharge structure

A recharge pit of size 1.5 × 1.5 × 0.8 m was dug in which two PVC tanks of 50 cm diameter and 60 cm height were placed keeping the open end facing the bottom of the pit. A PVC pipe of 63 mm diameter was connected from the overflow pipe of storage tank to the PVC tanks kept in the recharge pit. The area around the PVC tanks was back filled with boulders, gravels and coarse sand to facilitate the recharge and also to avoid clogging of the tanks, by the entry of mud in it.

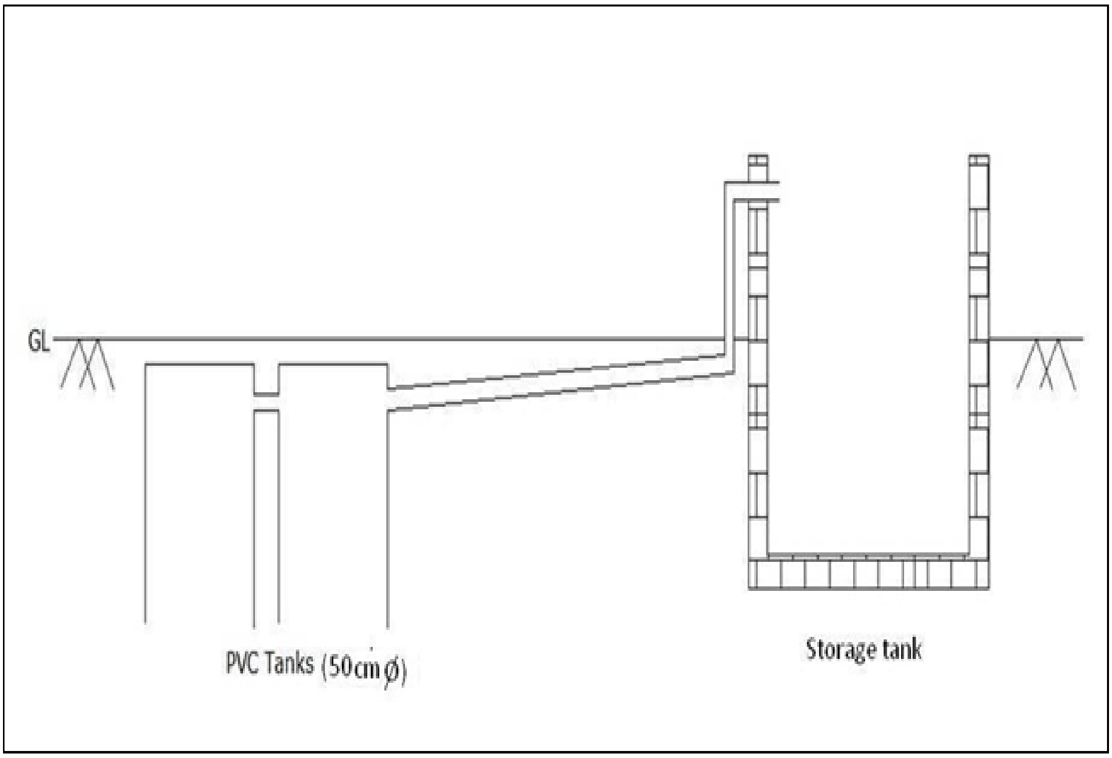

Fig. 4.4 Schematic diagram of underground recharge system

Plate 4.4 Underground recharge system

4.6 Quality of harvested water and efficiency of the filter

Water samples collected from the storage structure and various other sources were subjected to various analyses for their physical and chemical characteristics. The various quality parameters were determined by procedures as described earlier in section 3.4. The qualities of inflow and outflow of the filter were also analyzed to get information on the efficiency of filter designed as per procedure in 3.5. Comparisons of the qualities of harvested water with other sources gave a better acceptance for the system.

4.6.1 pH

The pH of the water collected was analyzed as per the procedure mentioned in 3.4.1.1 and the results showed that the water was slightly acidic and it may be due to atmospheric contamination (Table 4.6).

Table 4.6 pH of filtered water

Sample	pH
1	6.8
2	6.6

4.6.2 Total solids and Efficiency of the filter

Total solids in water were determined by gravimetric method as mentioned in the section 3.4.1.2. The suspended solids and dissolved solids were found separately by this method and then added to give total solids. The suspended solids were found to be in between 4 to 5ppm (Table 4.8) and dissolved solids were between 0 to 20 ppm (Table 4.10) for the filtered water. The net total solids in the filtered water were between 5 to 24 ppm (Table 4.11). The efficiency of the filter was found to be 90.2% (Table 4.9).

Table 4.7 Suspended solids in the inflow water to the filter

Sample	Initial weight (g)	Weight after drying (g)	Suspended solids (mg/l)
1	1.868	1.923	55
2	1.734	1.772	38
3	1.752	1.793	41

Table 4.8 Suspended solids in the filtered water

Sample	Initial weight (g)	Weight after drying (g)	Suspended solids (mg/l)
1	1.780	1.785	5
2	1.834	1.838	4
3	1.762	1.766	4

Table 4.9 Efficiency of the filter

Sample	Suspended solid before filtering (mg/l)	Suspended solid after filtering (mg/l)	Efficiency (%)	Average Efficiency (%)
1	55	5	90.90	90.2
2	38	4	89.47	
3	41	4	90.24	

Table 4.10 Dissolved solids in the filtered water

Sample	Initial weight (g)	Weight after drying (g)	Dissolved solids (mg/l)
1	45.021	45.021	0
2	47.835	47.836	10
3	46.942	46.944	20

Table 4.11 Total solids in the filtered water

Sample	Suspended solids (mg/l)	Dissolved solids (mg/l)	Total solids (mg/l)
1	5	0	5
2	4	10	14
3	4	20	24

4.6.3 Hardness

Total hardness of water is the sum of the concentrations of the metallic cations other than cations of the alkali metals expressed as equivalent calcium carbonate concentration. In most cases hardness is due to the presence of calcium and magnesium ions. The variation in total hardness was found to be in between 20 to 25 ppm (Table 4.12). It was found that this is below the prescribed limit of 75 ppm. The permanent hardness was found to be in between 15 to 20 ppm (Table 4.13) and temporary hardness was 5 ppm.

Table 4.12 Total Hardness

Sample No.	Volume of EDTA (ml)	Total hardness (ppm)
1	0.4	20
2	0.4	20
3	0.5	25

Table 4.13 Permanent Hardness

Sample No.	Volume of EDTA (ml)	Permanent hardness (ppm)
1	0.3	15
2	0.3	15
3	0.4	20

4.6.4. Chloride

Chloride is the common anion found in water. The presence of Chloride in water is mainly because of the dissolution of salt deposits and discharge of effluents. The chloride content from the water harvested was measured as per the procedure mentioned in 3.4.2.2. It is found to be within the prescribed limit of 250 ppm. The chloride content in the fresh water was found to be about 4 to 6 ppm (Table 4.14).

Table 4.14 Chloride in water

Sl. No.	Volume of Silver Nitrate (ml)	Amount of chloride (ppm)
1	0.3	6
2	0.2	4
3	0.2	4

4.7 Comparison of harvested water with water collected from different sources

4.7.1 Total solids

The test results (Table 4.15) showed that highest amount of total solids was found in pipe water, followed by well water, tube well water and finally water collected from the poly lined well. The amount of total solids was also found to be within the safe limits prescribed by the standards for drinking water.

Table 4.15 Comparison of Total solids in different sources of water

Sample	Suspended solids (mg)/l	Dissolved solids (mg/l)	Total solids (mg/l)
Pipe water	80	25	105
Well water	40	20	60
Tube well	30	20	50
Filtered roof water	4	10	14

4.7.2 Chloride

The permissible limit of chloride content in potable water is 250mg/ l and the results of chloride analysis showed that filtered water had the least amount of chloride compared to pipe water or tube well water or well water (Table 4.16).

Table 4.16 Comparison of chloride present in different sources of water

Sample	Titre value (ml)	Amount of chloride (ppm)
Pipe water	1.3	26
Well water	1.8	36
Tube well	0.8	16
Filtered roof water	0.2	4

4.7.3 Total hardness

The results showed that filtered water from the polylined well had much smaller quantity of total hardness and it was found to be within the permissible limit which is 75ppm (Table 4.17). This is due to the fact that the rain water is directly collected from the roof, before it get interacted with the soil and dissolve more impurities like in the case of well water.

Table 4.17 Comparison of hardness of different sources of water

Sample	Total hardness (ppm)	Permanent hardness (ppm)	Temporary hardness (ppm)
Pipe water	25	20	5
Well water	75	65	10
Tube well	35	25	10
Filtered roof water	20	15	5

The results of physical and chemical analysis done for water from various sources and that from the poly lined well showed that the water collected from the latter was of superior quality compared to the water collected from the other conventional sources. The comparison also showed that rainwater collected from the roof can be used to sort out the problems of poor water quality faced by the people living in converted paddy fields.

The entire RRWH system constructed was able to collect and store good quality water as required by the design to meet the water requirement of a family of four members for a dry spell of 150 days. The water stored did not show any deterioration in its quality and thus ensuring the suitability of the selected poly film as the lining material for water storage for longer periods. The filter designed could remove the impurities of rainwater to a larger extend (90.2%) with an appreciable filter rate of 3.83 $m^3/min/m^2$.

4.8 Economic analysis of the DRRWH System

4.8.1 Expenditure incurred

The details of the Expenditure incurred for the construction of the DRRWH System are shown in Table 4.18

Table 4.18 Expenditure incurred

Sl No	Particulars	Unit	No. of	Total
1	Clearing the site for storage tank			250
2	Excavation for the Storage tank			1700
	Leveling and Finishing Cost			1000
	Total			2950
3	Cost of Construction			
	Cost of Laterite Stones	17	250	4250
	Cost of Sand	600	2	1200
	Cement for Construction	320	4	1280
	Cost of Construction			3200
	Total			9930
4	Gutter Fitting			
	Cost of Gutter	85	20	1700
	End Connector and Water	120	3	360
	Cost of Metal Flat	30	18	540
	Gum and other connecting			400
	Installation Cost			800
	Miscellaneous Cost			500
	Total			430
5	Plumbing Materials for			
	63mm (2 ") PVC pipe	40	7	280
	63mm (2") elbow	24	4	96
	63mm (2") Bent	24	3	72
	63mm (2") Tee	30	1	30
	63mm End Cap	18	1	18
	63mm Wall Clamp	3	8	24
	Total			520
6	Cost of Filter			
	Coir fibre	50	0.5	25
	63mm (2") PVC pipe	40	1	40
	110mm (4") PVC pipe	110	1	110
	110mm - 63mm Reducer	45	2	90
	110mm (4") Female Threaded	120	1	120
	110mm (4") Male Threaded	100	1	100
	63mm (2") Tee	30	1	30
	63mm (2") elbow	24	1	24
	Total			539
7	UVA Clear LDPE Lining	48	100	4800
	Installation Cost			300
	Total			5100

10	Cost of Roof for the storage tank			
	Angle Iron	80	1.5	120
	3/4 " GI Pipe	88	23	2024
	1/2 " GI Pipe	65	6.5	422.5
	UVA Clear Sheet	48	14	672
	Aluminum Channel	48	12	576
	Zig Zag Spring	12	12	144
	Miscellaneous cost			500
	Total			4458.5
11	First Flush Diversion System			
	Excavation of pit			100
	Pit lining	48	4	192
	63mm (2") PVC pipe	40	0.5	20
	63mm (2")Ball Valve	280	1	280
	1/2 " Float Valve	700	1	700
	1/2 " Reducer	22	2	44
	Total			1336
12	Recharge System			
	Excavation of pit			300
	Plastic Drum	200	2	400
	63mm (2") PVC pipe	40	3.5	140
	63mm (2") Bent	24	2	48
	Total			888
	Grand Total			**30,021**

4.8.2 Economic analysis

Assumptions

- Expected life of the system is 25 years
- Annual growth rate of costs is 5%
- Annual growth rate of benefit is negligible
- The costs and benefits are discounted at 12%
- Salvage value is nil.
- Unit cost of water is 0.10 Rupees/litre.

Table 4.19 Economic analysis

1	2	3	4	5	6	7	8	9	10
Year	Capital Cost	O&M Cost	Total Cost	Return	Discount Factor	Present worth of Costs	Present worth of Benefits	Cash Flow	Net Present Worth (NPW)
1	30021	50	30071	16800	1	30071	16800	-13271	-13271
2		105.00	105	16800	0.895	94	15000	16695	14906
3		110.25	110	16800	0.797	88	13393	16690	13305
4		115.76	116	16800	0.712	82	11958	16684	11876
5		121.55	122	16800	0.636	77	10677	16678	10599
6		127.63	128	16800	0.567	72	9533	16672	9460
7		134.01	134	16800	0.507	68	8511	16666	8444
8		140.71	141	16800	0.452	64	7599	16659	7536
9		147.75	148	16800	0.404	60	6785	16652	6726
10		9307.97	9308	16800	0.361	3357	6058	7492	2702
11		162.89	163	16800	0.322	52	5409	16637	5357
12		171.03	171	16800	0.287	49	4830	16629	4780
13		179.59	180	16800	0.257	46	4312	16620	4266
14		188.56	189	16800	0.229	43	3850	16611	3807
15		18809.3	18809	16800	0.205	3849	3438	-2009	-411
16		207.89	208	16800	0.183	38	3069	16592	3031
17		218.29	218	16800	0.163	36	2740	16582	2705
18		229.20	229	16800	0.146	33	2447	16571	2413
19		240.66	241	16800	0.130	31	2185	16559	2153
20		15161.7	15162	16800	0.116	1760	1951	1638	190
21		265.33	265	16800	0.104	28	1742	16535	1714
22		278.60	279	16800	0.093	26	1555	16521	1529
23		292.53	293	16800	0.083	24	1388	16507	1364
24		307.15	307	16800	0.074	23	1240	16493	1217
25		322.51	323	16800	0.066	21	1107	16477	1086
Total		**47396**	**77417**	**420000**		**40092**	**147577**	**342583**	**107484**

Equations

- Column 4, Total cost = column 2 + column 3
- Column 5, Return = Annual water yield X Unit cost
- Column 6, Discount factor $= \frac{1}{\left(1+\frac{\text{Discount rate}}{100}\right)^{n-1}}$
- Column 9, Cash flow= Column 5- Column 4
- Column 7, Present worth of Costs = Column 4 X Column 6
- Column 8, Present worth of Benefits = Column 5 X Column 6
- Column 10, Net Present Worth (NPW) = Column 9 X Column 6
- Benefit-cost ratio = Column 8 / Column 7
- Internal Rate of Returns = Discount rate at which NPW become Zero.

By taking annual rainfall depth as 3m and runoff coefficient as 0.8 , for a roof area of 70 m^2 we get an annual yield of 1,40,000 litres . Unit cost of water has been taken as 0.10 Rupees per litre. For a project life of 25 years we got the net present worth as Rs.1, 07,484. Benefit-cost ratio and internal rate of return of the project are found to be four and 86% respectively. As per World Bank recommendations, the Benefit-cost ratio is greater than one, and internal rate of return is greater than15%, if the project is cost effective and profitable.

4.9 Maintenance package

Maintenance of roof top rain water harvesting system (RRWH) is easy and cheap. As the entire system is house hold based, it becomes one of the assets of the house and hence could be maintained best by the users themselves. It requires continuous care and maintenance just as any other asset in the house. In fact, maintenance of RRWHS should get priority over the other house hold items, as it is necessary for the good health of all the family members. Cleanliness of surroundings as well as the system including its various components such as roof, gutters, filtration unit and the storage tank, will determine the quality of water throughout the dry spell, for drinking and cooking purposes of the house. The recommended maintenance package includes the following measures.

1. Clean the roof prior to the onset of monsoon to remove dirt and debris if present, which may clog the collection and conveyance system.
2. Clean the filter twice in a month by back washing. Flush out the stagnant water if present, by opening the ball valve provided.
3. Clean the tank before the onset of monsoon. Care should be taken not to cause any harm to the lining while cleaning.
4. Lining should not be damaged while drawing out water from the tank. So it is recommended to use rubber buckets.
5. It would be better to provide netting along the gutter to prevent it from clogging by leaves or other obstacles.
6. The lining material should be replaced every 10 years as the life of the material is only 10 years.
7. Change the coir fibre twice in a year.

4.10 Computer program for the design of RRWH system

A computer program was developed in Visual basic 6 which gives various data for the design and operation of a rain water harvesting system from the inputs entered. The codes for this are given in Appendix I. The basic inputs given for the design of storage structure are the roof area, runoff coefficient, number of persons, per capita use, water year and period of dry spell

The major output obtained are the volume of the tank, the design volume by giving an allowance of 20% to the required volume, the filter area required for efficient filtration, peak rate of discharge, approximate cost of construction, cumulative rainfall depth, cumulative harvest of water, cumulative volume collected in the storage tank, cumulative water recharged, cumulative consumption of water, and water remaining at the end of the water year. The software also shows the daily depth of rainfall, peak intensity and total annual rainfall for four years.

The assumpions considered for the preparation of this program were:

1. The water year starts from June 1^{st} and ends on May 31^{st} of the very next year.

2. The daily water use for the monsoon season, i.e. from June 1^{st} to September 30th is twice the daily water consumption provided that the cumulative volume collected in the storage tank is greater than or equal to 90% of the total volume of the storage tank. Otherwise the daily water use is considered as zero for this period.

3. The daily water use for the period from October 1^{st} to January 15^{th} of the next year is considered as equal to the daily water consumption, provided the stored volume of water in the tank is greater than 90% of the total volume of the storage tank. Otherwise the daily water use is considered as zero for this period.

4. The daily water use in dry spell is taken as the daily water consumption.

The user interface of the program is as shown below.

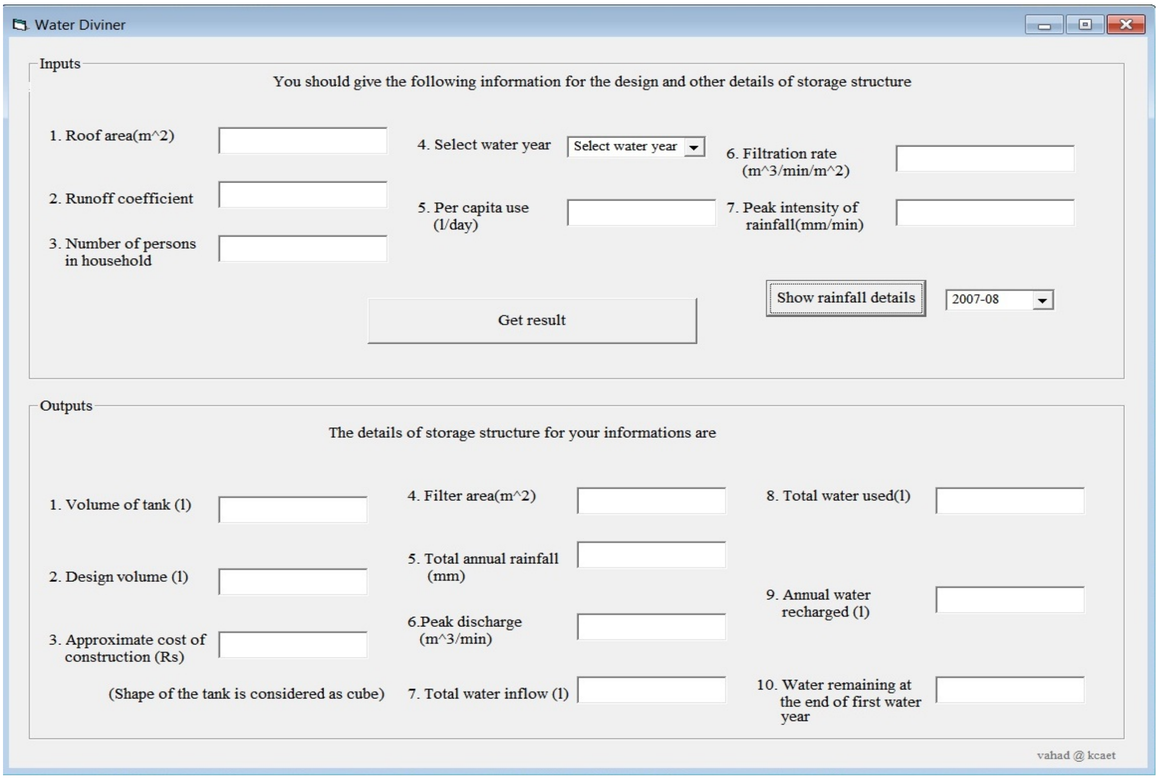

Fig 4.5 User interface of the program

CHAPTER 5

SUMMARY AND CONCLUSIONS

Collecting the rain that falls on a building and using the same for various purposes is a simple concept. Since the rain you harvest is independent of any centralized system, you are promoting self-sufficiency and helping to foster an appreciation for this essential and precious resource. The collection of rain water not only leads to conservation of water but also energy since the energy input required to operate a centralized water system designed to treat and pump water over a vast service area is bypassed. Rain water harvesting also reduces local erosion and flooding caused by runoff from impervious cover such as pavement and roofs, as some rain is instead captured and stored. Thus, the storm water run-off, the normal consequence of rain fall, which picks up contaminants and degrades our water ways, becomes captured rainfall which can then fulfill a number of productive use. The collection of rain water from the rooftop and using it for domestic purposes at its region of collection is called rooftop rain water harvesting. In our work roof of the smithy shop in campus is considered as catchment area. Thus water is collected from an area of $70m^2$ contributed by the roof

The collected water should be effectively stored for the future use. Collection in large containers is not feasible as they grab much space and money. So, an underground storage tank, lined with polyfilm was selected. The storage tank has been provided with a portable shed roof (with GI pipe framework) to prevent any contamination of stored water. UVA Clear LDPE sheet of 200 micron thickness was selected for lining and covering the roof of the water storage tank. $100m^2$ polyfilm has been used for lining the storage tank and 13.8 m^2 for covering the roof. An upward flow type filter, having alternate layers of coir fibre 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. An automated first flush diversion system was also installed to prevent the entry of first rainwater after a dry season to the filter, so that the excess dirt load is reduced. An underground recharge tank has been constructed to recharge the ground water using the overflow, without losing the land area. The results of physical and chemical analysis done for water from various sources and that from the poly lined well showed that the water collected from the latter was of superior quality compared to the water collected from the other conventional sources. The entire RRWH system constructed was able to collect and store good quality water as required by the design to meet the water requirement of a family of four members for a dry spell of 150 days. The water stored did not show any deterioration in its quality and thus ensuring the suitability of the selected poly film as the lining material for water storage for longer periods. From the economic analysis of the project, we found that, for a unit cost of Rs.0.10 per litre of water, Net present worth, Benefit Cost ratio and internal rate of returns were Rs.1,07,484.,four and 86% respectively, which indicates the profitability of the project.

A computer program was developed in Visual basic 6 which gives various outputs for the design and operation of the rain water harvesting system. The basic inputs given for the design of storage structure are the roof area, runoff coefficient, number of persons, per capita use, water year and dry spell. The major output obtained were the volume of the tank, the design volume by giving an allowance of 20% to the required volume, the filter area required for efficient filtration, peak rate of discharge, approximate cost of construction, cumulative rainfall depth, cumulative harvest of water, cumulative volume collected in the storage tank, cumulative water recharged, cumulative consumption of water, and water remaining at the end of the water year. The software also shows the daily depth of rainfall, peak intensity and total annual rainfall for four years.

The specific conclusions that are drawn out from the current study are:

1. The designed DRRWH system could reduce the unit cost of water to 10 paise per litre which is the lowest when compared to other existing RRWH systems.

2. Study proved that the UVA Clear polyfilm is a good option as a lining material. It has the required strength and durability. There is no quality deterioration for the stored water. Also it helped in bringing down the cost of the storage tank to a great extent.

3. By analyzing the water, it was seen that the coir and activated carbon filter media was able to remove about 90.2 % of the impurities from the roof water and the water collected could meet the required quality standards.

Hence it can be concluded that the designed RRWH system can be strongly recommended for households facing the problems of water scarcity and quality deterioration.

Scope for future work

1. This study can be extended to analyze the long term effect of polyfilm on the quality of stored water.
2. The design of the tank roof can be modified by considering the wind effects.
3. Shotcreting can be adopted to line the vertical surfaces of the storage tank, as the polyfilms are suitable only for stable soil surfaces.
4. First flush diversion system may breed mosquitoes. So a modified system can be introduced considering the health hazards.

REFERENCE

Ahamad,I., Ahamad,C.B., Butt,H.N., Zuberi,F.A. and Bodia,M.A. 1993. Studies on the performance of various lining materials. Proc. Inter. workshop on canal lining and seepage. Lahore, Pakistan, 301-321.

Ahmed,N. 1993. An over view of canal lining experience in Pakistan. Proc. Inter. workshop on canal lining and seepage. Lahore, Pakistan, 223-240.

Ambili,P.T. and Biju,S. 2002. Evaluation of aquifer parameters from pumping test data. Unpublished B.Tech project report, K C A E T, K A U, Tavanur, Malappuram.

Athavale,R.N. 2002. Rainwater harvesting. Water harvesting and sustainable supply in India. Rawat publications, pp.50-58.

Bineesh,S., Nisha,T.V. and Preethi,A. 2004. Assessment of salient features of groundwater resources – A case study in humid tropical region. Unpublished B.Tech project report, K C A E T, K A U, Tavanur, Malappuram.

Chattopadhyay,S. 2001. Community inventorisation. Making water everybody's business - practice and policy of water harvesting.: 141-142.

Dwivedi,.N. and Sarkar,T.K. 1983. Lining of farm ponds. J. Irrigation and Power. 40(2): 177-180.

Foel,H. 2001. Ground water recharge characteristics in a semi arid environment of south west Idaho. 32(2): 180-186.

Gogte,A. 2001. Redeeming Negev's heritage- Making water everybody's business- Practices and policy of water harvesting: 186-188.

Kavitha,M.N., Sanfred,J.L. and Sini,K. 2005. Recharge and discharge studies in laterite soils.

Kraatz,D.B. 1977, Irrigation canal lining. *No.1*, FAO, Rome. : 3-49.

Jyothison,G., Lakshmi,D.S. and Sreesha,P. 2004. Assessment of roof water harvesting potential and recharge pit design. Unpublished B.Tech project report, K C A E T, K A U, Tavanur, Malappuram.

Michael, A. M. 2008. Irrigation theory and practice. Vikas publishing house, Pvt. Ltd. Noida (UP).

Preman,K.P. 2001. The Kerala experience. Making water everybody's business- Practices and policy of water harvesting: 146-148.

Pandya,S. and Sharma,V.K. 1986. Socio-economic impact of Ramganga command area, Development project and economics of brick lining of field channels. J. Irrigation and Power. 43(4): 341-346.

Punmaya, B.C. 2001. Soil mechanics and foundation, Laxmi Publications pvt ltd. New Delhi. pp.125-129.

Rangwala,S.C. 2003. Water supply and sanitary engineering. Charotor publishing house, Anand. pp.115-160, 595-600.

Ranjan,S. 2001. Dihra's dividends. Making water everybody's business- Practices and policy of water harvesting: 122-124.

Siddique,M., Pasha,F.H. and Chaudry,A.M. 1993. Seepage loss measurements on Chashma Right Bank canal. Proc. Inter.Workshop on Canal Lining and Seepage. Lahore, Pakistan: 197-218.

Suresh,R. 2000. Soil and water conservation engineering. Standard publishers. Delhi. pp.45-50, 523-531.

Tiwari,K.N., Kumar,S. and Kumar,J.1990. Performance of lining materials in experimental field channels. Proc. 11^{th} Inter. Congress on the Use of Plastics in Agriculture, New Delhi, India : 31-36.

Taley,S.M. and Kohale,S.K. 1986. Performance of the irrigation channel lining materials. *P.K.*V. Research J. 10(2): 138-140.

Tiwari,K.N. and Pant,N. 1990. Performance evaluation of lining materials for seepage control from farm ponds. Proc. 11th Inter. Congress on the use of Plastics in Agriculture. New Delhi, India: c.25-c.30.

Tiwari,K.N., Kumar,S. and Kumar,J, 1990. Performance of lining materials in experimental field channels. Proc. 11th Inter. Congress on the Use of Plastics in Agriculture, New Delhi, India: 31-36.

APPENDICES

Computer program in Visual Basic 6 language form the design of DRRWH

```
Public Sub Result_Click()
Dim ind, a As Integer
Dim total, antotal, dailcon, dailvol, cumvol As Double
Dim cumhar, cumcon, dailrechg, twr, wrm As Double
Dim dailhar(13, 32) As Double
Dim i, j As Integer
Dim count, big As Double
Dim fa, pd, ra, rc, np, pc, ps, X, vt, dv, ac, pi, fr As Double
If text1.Text = "" Then
   MsgBox "Roof area is not entered"
ElseIf text2.Text = "" Then
   MsgBox "Runoff coefficient is not entered"
ElseIf text3.Text = "" Then
   MsgBox "Number of persons in a household is not entered"
ElseIf text4.Text = "" Then
   MsgBox "Per capita use is not entered"
ElseIf text5.Text = "" Then
   MsgBox "Filtration rate is not entered"
ElseIf text6.Text = "" Then
   MsgBox "Peak intensity of rainfall is not entered"
End If
```

```
If Combo1.ListIndex = 0 Then
'***************************************************
'Rainfall details
'***************************************************
'****************************************
'peak intensity and dryspell period finding
'******************************************
'ps- period of dry spell
'****************************************

'**************************************
'calculations

'**************************************
'ra- roof area
'rc- runoff coefficient
'np- no of persons
'pc- percapita use
'x- ra x rc
'fr- filtration rate
'pd- peak discharge
'pi- peak intensity of rainfall
'fa- filter area
'vt- vol of tank
```

```
'dv- design volume

'ac- approximate cost of construction

'***************************************

ra = Val(text1.Text)

rc = Val(text2.Text)

np = Val(text3.Text)

pc = Val(text4.Text)

fr = Val(text5.Text)

pi = Val(text6.Text)

X = 0

vt = 0

dv = 0

X = ra * rc

vt = np * pc * ps

dv = 1.2 * vt

ac = dv * 1.11

text7.Text = vt

text8.Text = dv

text9.Text = ac

pd = ((pi * X) / 1000)

text12.Text = pd

fa = pd / fr

text10.Text = fa

'*********************************************

'Water consumption calculation
```

```
'*********************************************

'total- total monthly rainfall

'antotal- total annual rainfall

'dailcon- daily water consumption

'dailvol- daily volume collected in tank

'cumvol-cumulative volume in tank

'cumhar-cumulative harvest of water

'cumcon-cumulative consumption of water

'i,j- counters

'dailrechg-daily recharge of water

'twr-total water recharged

'wrm-water recharged at the end of water year

'********************************************

total = 0

antotal = 0

dailcon = 0

dailvol = 0

cumvol = 0

cumhar = 0

dailrechg = 0

twr = 0

wrm = 0

i = 1

j = 1

dailhar(i, j) = 0
```

```
Do While (i < Rainfall78.grid78.Cols)
    Do While (j < Rainfall78.grid78.Rows)
        Rainfall78.grid78.Col = i
        Rainfall78.grid78.Row = j
        total = total + Val(Rainfall78.grid78.Text)
        dailhar(i, j) = X * Val(Rainfall78.grid78.Text)
        cumhar = cumhar + dailhar(i, j)
        dailvol = dailhar(i, j) - dailcon
        cumvol = cumvol + dailvol
        j = j + 1
        If (cumvol > dv) Then
            dailrechg = cumvol - dv
            twr = twr + dailrechg
            cumvol = dv
        Else
            dailrechg = 0
        End If

        If (i >= 1 And i <= 4 And cumvol >= (0.9 * dv)) Then
            dailcon = 2 * pc * np
            cumcon = cumcon + dailcon
        End If

        If (i > 4 And i <= 7 And cumvol >= (0.9 * dv)) Then
```

```
        dailcon = pc * np
        cumcon = cumcon + dailcon
    End If

    If (i > 7 And cumvol >= (pc * np)) Then
      dailcon = pc * np
      cumcon = cumcon + dailcon

    End If

    If (i > 7 And cumvol > 0) Then
      dailcon = cumvol
      cumcon = cumcon + dailcon
    End If
    If (i <= 7 And cumvol < (0.9 * dv)) Then
      dailcon = 0
      cumcon = cumcon + dailcon
    End If

  Loop
    i = i + 1
    j = 1
    antotal = antotal + total
    total = 0
```

```
Loop

wrm = cumhar - (twr + cumcon)
If (wrm <= 0) Then
   wrm = 0
End If
text11.Text = antotal
text13.Text = cumhar
text14.Text = twr
text15.Text = cumcon
text16.Text = wrm
ElseIf Combo1.ListIndex = 1 Then
'***************************************************
'Rainfall details
'***************************************************
ind = 1
a = 2
'****************************************
'peak intensity and dryspell period finding
'******************************************
'ps- period of dry spell
'****************************************
ind = 1
a = 1
count = 0
```

```
ps = 0


Do While (ind < Rainfall89.grid89.Cols)
    Do While (a < Rainfall89.grid89.Rows)
    Rainfall89.grid89.Col = ind
    Rainfall89.grid89.Row = a
    If (Val(Rainfall89.grid89.Text) <> 0) Then
    count = count + 1
    End If
    a = a + 1
    Loop
    a = 1
    ind = ind + 1
Loop


    ps = (365 - count)


'**************************************
'calculations


'**************************************
'ra- roof area
'rc- runoff coefficient
'np- no of persons
'pc- percapita use
```

```
'x- ra x rc

'fr- filtration rate

'pd- peak discharge

'pi- peak intensity of rainfall

'fa- filter area

'vt- vol of tank

'dv- design volume

'ac- approximate cost of construction

'***************************************

ra = Val(text1.Text)

rc = Val(text2.Text)

np = Val(text3.Text)

pc = Val(text4.Text)

fr = Val(text5.Text)

pi = Val(text6.Text)


X = 0

vt = 0

dv = 0

X = ra * rc

vt = np * pc * ps

dv = 1.2 * vt

ac = dv * 1.11

text7.Text = vt

text8.Text = dv
```

```
text9.Text = ac

pd = ((pi * X) / 1000)

text12.Text = pd

fa = pd / fr

text10.Text = fa


'*******************************************

'Water consumption calculation

'********************************************

'total- total monthly rainfall

'antotal- total annual rainfall

'dailcon- daily water consumption

'dailvol- daily volume collected in tank

'cumvol-cumulative volume in tank

'cumhar-cumulative harvest of water

'cumcon-cumulative consumption of water

'i,j- counters

'dailrechg-daily recharge of water

'twr-total water recharged

'wrm-water recharged at the end of water year


'*******************************************

total = 0

antotal = 0

dailcon = 0
```

```
dailvol = 0

cumvol = 0

cumhar = 0

dailrechg = 0

twr = 0

wrm = 0

i = 1

j = 1

dailhar(i, j) = 0


Do While (i < Rainfall89.grid89.Cols)

    Do While (j < Rainfall89.grid89.Rows)

        Rainfall89.grid89.Col = i

        Rainfall89.grid89.Row = j

        total = total + Val(Rainfall89.grid89.Text)

        dailhar(i, j) = X * Val(Rainfall89.grid89.Text)

        cumhar = cumhar + dailhar(i, j)

        dailvol = dailhar(i, j) - dailcon

        cumvol = cumvol + dailvol

        j = j + 1



        If (cumvol > dv) Then

            dailrechg = cumvol - dv

            twr = twr + dailrechg
```

```
    cumvol = dv
Else
    dailrechg = 0
End If

If (i >= 1 And i <= 4 And cumvol >= (0.9 * dv)) Then
    dailcon = 2 * pc * np
    cumcon = cumcon + dailcon
End If
        If (i > 4 And i <= 7 And cumvol >= (0.9 * dv)) Then
        dailcon = pc * np
        cumcon = cumcon + dailcon
End If
        If (i > 7 And cumvol >= (pc * np)) Then
    dailcon = pc * np
    cumcon = cumcon + dailcon
        End If

If (i > 7 And cumvol > 0) Then
    dailcon = cumvol
    cumcon = cumcon + dailcon
End If
If (i <= 7 And cumvol < (0.9 * dv)) Then
    dailcon = 0
    cumcon = cumcon + dailcon
```

```
        End If



    Loop
        i = i + 1
        j = 1
        antotal = antotal + total
        total = 0

Loop

wrm = cumhar - (twr + cumcon)



If (wrm <= 0) Then
    wrm = 0
End If
text11.Text = antotal
text13.Text = cumhar
text14.Text = twr
text15.Text = cumcon
text16.Text = wrm
ElseIf Combo1.ListIndex = 2 Then
'****************************************
'peak intensity and dryspell period finding
```

```
'*****************************************
'ps- period of dry spell
'***************************************
ind = 1
a = 1
count = 0
ps = 0

Do While (ind < Rainfall910.grid910.Cols)
    Do While (a < Rainfall910.grid910.Rows)
    Rainfall910.grid910.Col = ind
    Rainfall910.grid910.Row = a
    If (Val(Rainfall910.grid910.Text) <> 0) Then
    count = count + 1
    End If
    a = a + 1
    Loop
    a = 1
    ind = ind + 1
Loop

    ps = (365 - count)

'*************************************
'calculations
```

```
'************************************
'ra- roof area
'rc- runoff coefficient
'np- no of persons
'pc- percapita use
'x- ra x rc
'fr- filtration rate
'pd- peak discharge
'pi- peak intensity of rainfall
'fa- filter area
'vt- vol of tank
'dv- design volume
'ac- approximate cost of construction
'*************************************
ra = Val(text1.Text)
rc = Val(text2.Text)
np = Val(text3.Text)
pc = Val(text4.Text)
fr = Val(text5.Text)
pi = Val(text6.Text)

X = 0
vt = 0
dv = 0
X = ra * rc
```

```
vt = np * pc * ps

dv = 1.2 * vt

ac = dv * 1.11

text7.Text = vt

text8.Text = dv

text9.Text = ac

pd = ((pi * X) / 1000)

text12.Text = pd

fa = pd / fr

text10.Text = fa

'********************************************

'Water consumption calculation

'*********************************************

text11.Text = antotal

text13.Text = cumhar

text14.Text = twr

text15.Text = cumcon

text16.Text = wrm

ElseIf Combo1.ListIndex = 3 Then

'*************************************************

'Rainfall details

'*************************************************

MsgBox "Rainfall data till November24 is only available. This design is based on that data "

ind = 1

Do While (ind < Rainfall1011.grid1011.Cols)
```

```
Rainfall1011.grid1011.Row = 0

Rainfall1011.grid1011.Col = ind

Rainfall1011.grid1011.Text = month(ind)

ind = ind + 1

Loop

ind = 1

Do While (ind < 32)

Rainfall1011.grid1011.Col = 0

Rainfall1011.grid1011.Row = ind

Rainfall1011.grid1011 = Str(ind)

ind = ind + 1

Loop

ind = 1

a = 1

count = 0

ps = 0


Do While (ind < Rainfall1011.grid1011.Cols)

   Do While (a < Rainfall1011.grid1011.Rows)

   Rainfall1011.grid1011.Col = ind

   Rainfall1011.grid1011.Row = a

   If (Val(Rainfall1011.grid1011.Text) <> 0) Then

   count = count + 1

   End If

   a = a + 1
```

```
    Loop
    a = 1
    ind = ind + 1
Loop
     ps = (365 - count)
    '**************************************
'calculations
'**************************************
text11.Text = antotal
text13.Text = cumhar
text14.Text = twr
text15.Text = cumcon
text16.Text = wrm
Else
 MsgBox "Select water year"
End If
End Sub
'*******************************************
'To show rainfall details
'*********************************************
'**********************************************
'Rainfall details
'*********************************************
ind = 1
Rainfall78.Show
```

```
'*****************************************************


ElseIf (Combo2.ListIndex = 1) Then

'************************************

'Disply months

'************************************

Rainfall89.grid89.Row = 32

Rainfall89.grid89.Text = "Total"

'*************************************************

'Rainfall details

'*************************************************

Rainfall89.Show

'*************************************************

ElseIf (Combo2.ListIndex = 2) Then

Rainfall1011.Show

Else

MsgBox "Select Year"

End If

End Sub
```