International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 1, Issue 2, February 2014)

Sustainable Development of Rain Water Harvesting System for the Multi-storeyed Apartments of Indian Cities

- Solution for Indian Domestic Water Needs

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***Abstract*: The present study aims to provide some guidelines for economic rainwater harvesting system, for urban areas, for people residing in multi storied apartments in the area of Hyderabad. These guidelines were formulated using existing data, through analysis of rainwater harvesting and comparative studies of Rapid Depletion and Rational Methods. Data from secondary sources have also been used for the purpose. Based on these guidelines, a mathematical model has been developed to figure out certain sizes for collection of rainwater and designing of rain water harvesting tank and filtration tank are also carried out for a multi-storeyed residential apartment.**

Index Terms— Rapid Depletion, Rational Methods, Water Quality Standards, Rain Fall Data, Catchment, RWH tank

1. INTRODUCTION:

Living creatures of the universe are made of five basic elements, viz., Earth, Water, Fire, Air and Sky, Obviously, water is one of the most important elements and no creature can survive without it. Despite having a great regard for water, we seem to have failed to address this sector seriously. Human being could not save and conserve water and it sources, probably because of its availability in abundance. But this irresponsible attitude resulted in deterioration of water bodies with respect to quantity and quality both. Now, situation has arrived when even a single drop of water matters. However "Better late than never", we have not realized the seriousness of this issue and initiated efforts to overcome those problems.

Water is essential to all life forms on earth - human, animal and vegetation. It is therefore important that adequate supplies of water be developed to sustain such life. Development of water supplies should, however, be undertaken in such a way as to preserve the hydrological balance and the biological functions of our ecosystems. Consequently, the human endeavour in the development of water sources must be within the capacity of nature to replenish and to sustain. If this is not done, costly mistakes can occur with serious consequences. The application of innovative technologies and the improvement of indigenous ones should therefore include management of the water sources to ensure sustainability and to safeguard the sources against pollution. As land pressure rises, cities are growing vertical and in countryside more forest areas are encroached and being used for agriculture.

In India the small farmers depend on Monsoon where rainfall is from June to October and much of the precious water is soon lost as surface runoff. There is now increasing interest in the low cost alternative-generally referred to as 'Rain Water Harvesting' (RWH). Water harvesting is the activity of direct collection of rainwater, which can be stored for direct use or can be recharged into the groundwater. Water harvesting is the collection of runoff for productive purposes. Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water for us. Rivers, lakes and groundwater are all secondary sources of water. In present times, we depend entirely on such secondary sources of water. Water harvesting is to understand the value of rain, and to make optimum use of rainwater at the place where it falls.

Water is an important element for all human beings in the world. Our body consists mostly of water. We need water for drinking, cooking, washing, agriculture and to run our industries. We usually take it for granted because of its availability; but when in scarcity it becomes our most precious resource. Every raindrop that falls from the cloud is very soft and the cleanest water sources in this world (Texas Water Development Board, 2005). The falling raindrop acquires slight acidity as it dissolves carbon dioxide and nitrogen (MHLG, 2008). Rainwater is a part of hydrologic cycle; the never-ending exchange of water from the atmosphere to the ocean and back again as rainwater. The precipitation like hail, rain, sleet, snow and all the consequently movement of water in nature forms are from part of this cycle.

Ground water resource gets naturally recharged through percolation. But due to indiscriminate development and rapid urbanization, exposed surface for soil has been reduced drastically with resultant reduction in percolation of rainwater, thereby depleting ground water resource. Rainwater harvesting is the process of augmenting the natural filtration of rainwater in to the underground formation by some artificial methods. "Conscious collection and storage of rainwater to cater to demands of water, for drinking, domestic purpose & irrigation is termed as Rainwater Harvesting".

Rainwater can be captured by using the rainwater harvesting system. Generally, rainwater harvesting system is the direct collection of rainwater from roofs and other purpose built catchments, the collection of sheet runoff from man-made ground or natural surface catchments and rock catchments for domestic, industry, agriculture and environment use. The systems can be categorized as small, medium and large scale (Gould 1999). Normally, the size of rainwater harvesting was based on the size of catchment area (Thamer*et al*., 2007). In scientific term, rainwater harvesting refers to collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions, aimed at conservation and efficient utilization of the limited water endowment of physiographic unit as a watershed (Agrawal and Narain, 1999).

2. RAIN WATER HARVESTING METHODOLOGY:

Roof Rain Water Harvesting- The roof top area is used as the catchment area for the rainfall in urban areas. The collection and storage sizes and systems need to be optimized for the Rainwater Harvesting systems in such cases.

Watershed based Rain Water harvesting- A watershed consists of a land and water region bounded by ridge lines or other such drainage divides within which the water flowing as surface runoff gets collected and flows out of the watershed along a network of channels or through a single outlet into a lager river (or) lake. Rainwater harvesting for a common single watershed is generally taken up in most of the rural areas. As the cost of land is less and it is available in plenty, surface spreading techniques are generally effectively adopted in such regions.

Components:

A rainwater harvesting system comprises of components for - transporting rainwater through pipes or drains, filtration, and tanks for storage of harvested water. The common components of a rainwater harvesting system are

Catchments: The surface which directly receives the rainfall and provides water to the system is called catchment area. It can be a paved are like a terrace or courtyard of a building, or an unpaved area like a Lawn or open ground. A roof made of reinforced cement concrete (RCC), galvanized iron or corrugated sheets can also be used for water harvesting.

Coarse Mesh: It prevents the passage of debris, provided in the roof.

Gutters: Channels which surrounds edge of a sloping roof to collect and transport rain water to the storage tank. Gutters can be semi-circular or rectangular and mostly made locally from plain galvanized iron sheet. Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed mainly depends on the construction of the house, mostly iron or timber brackets are fixed into the walls.

Conduits: Conduits are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Commonly available conduits are made up of material like polyvinyl chloride (PVC) or galvanized iron (GI).

First-flushing: A first flush device is a valve which ensures flushing out of first spell of rain away from the storage tank that carries a relatively larger amount of pollutants from the air and catchment surface.

Filters: The filter is used to remove suspended pollutants from rainwater collected from rooftop water. The Various types of filters generally used for commercial purpose are Charcoal water filter, Sand filters, Horizontal roughing filter and slow sand filter.

Storage facility: There are various options available for the construction of these tanks with respect to the shape, size, material of construction and the position of tank and they are:-

Shape: Cylindrical, square and rectangular.

Material of construction: Reinforced cement concrete (RCC), masonry, Ferro cement etc.

Position of tank: Depending on land space availability these tanks could be constructed aboveground, partly underground or fully underground. Some maintenance measures like disinfection and cleaning are required to ensure the quality of water stored in the container. If harvested water is decided to recharge the underground aquifer/reservoir, then some of the structures mentioned below are used.

3. PROBLEM STATEMENT:

The purpose of this study is to assess sustainable rainwater harvesting solution for multi-storeyed residential apartments in Hyderabad.

Research Objectives:

International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 1, Issue 2, February 2014)

1. To identify and analyse the rainwater harvesting methods of India.

2. Analyse the significance of rainwater harvesting in the urban residential areas of Hyderabad.

3. Develop a solution for rainwater harvesting solution for a typical multi-storeyed residential apartment in Hyderabad.

Delimitations:

1. The research will be confined only to the urban area of Hyderabad.

2. The study will be confined to residential apartments of Hyderabad.

3. The study will be confined to six storey apartment buildings of Hyderabad.

Assumptions:

1. No environmental or other contamination other than those from the catchment area will be present in the harvested rainwater.

2. The rainwater harvesting method is socially accepted in the study area.

3. The per capita water consumption is assumed to be 135lpcd

4. STUDY AREA & DATA COLLECTION:

4.1 Study Areas:

As discussed earlier in the section of introduction–importance of rainwater harvesting at Urban areas of Hyderabad, we clearly came to know the all the advantages which we can draw out by implementing this small but highly efficient technique in the campus. Thus to increase the potential, benefits of this system and draw maximum advantages from it, we need to have large rooftop areas which will be going to act as catchment areas. More the catchment areas more will be the surface runoff and thus more will be the amount of harvested water.

4.2 Data Collection:

4.2.1Topography & Geological Conditions:

Hyderabad Latitude and Longitude

The latitude and longitude of Hyderabad can be projected as 17° 22' 31" N and 78° 28' 27" E. The city is nestled on the Deccan Plateau and is positioned at a height of around 500 meters from the sea level. Major parts of the city feature rocky terrain and in some parts hills can also be noticed.

Latitude and Longitude of Hyderabad Airport

Along with the latitude and longitude of the city, you can also know about the area location of the airport in Hyderabad, which is situated at 25° 19' 20" N and 68° 21' 50" E. From here, you can measure the distance of other locations and simultaneously calculate the time that would be taken in traveling.

4.2.2. Geographical Conditions and Demographics of Hyderabad

Apart from having information on the Hyderabad latitude and longitude, it is interesting to have certain information on its geographical features as well. The city of Hyderabad is situated at a height of 1,640 ft above the sea level and its landscape is primarily dotted with rocky trails. However, some parts of the city feature hills also.

4.3 Rain Fall Data Collection:

Average annual rainfall ranges between 80-90 cm. The average monthly rainfall data are being taken from the world weather online. Hyderabad has a uniform average rainfall throughout the city in all location. Thus monthly rainfall data of the Hyderabad city is given below in the table which is assumed to be same for the all locations of the Hyderabad.

Table1.
Monthly Rain Fall Data of Hyderabad

Month	Precipitation (in mm)	Average Rain Fall Days
January	13.4	3
February	12.6	1
March	23.5	3
April	22.0	6
May	40.3	8
June	113.8	19
July	172.8	23
August	230.1	24
September	125.3	17
October	102.4	13
November	43	4
December	6.6	1

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5. METHODOLOGY:

On the basis of experimental evidence, Mr. H. Darcy, a French scientist enunciated in 1865, a law governing the rate of flow (i.e. the discharge) through the soils. According to him, this discharge was directly proportional to head loss (H) and the area of cross-section (A) of the soil, and inversely proportional to the length of the soil sample (L). In other words,

$$Q \propto H / L$$

Q = Run Off

Here, H/L represents the head loss or hydraulic gradient (I),

K is the co-efficient of permeability

Hence, Finally,

$$Q = K . I . A$$

The total amount of water that is received from rainfall over an area is called the rainwater legacy of that area. And the amount that can be effectively harvested is called the **water harvesting potential**. The formula for calculation for harvesting potential or volume of water received or runoff produced or harvesting capacity is given as:

Harvesting Potential or Volume of Water Received (m^3)
=
Area of Catchment (m^2) X Amount of Rain Fall (mm) X Runoff Coefficient

5.1. Methods for Storage of Harvested Rain Water in the Tank:

Finally, we need to store the water which is obtained from the rooftop areas of the different buildings. The volume of tank which stores the harvested water will be directly proportional to the total volume of water harvested.

Technically, there are two types of methods for distributing the harvested rainwater:-

- RATIONING METHOD (RM)
- RAPID DEP LETION METHO D (RDM)

The detail calculation is carried out to get the valuable steps. Later on, the se crucial steps are again applied to all other building and number of days for consumption of stored water is calculated by using both of these methods.

5.1.1. Rationing Method (RM):

The Rationing method (RM) distributes stored rainwater to target public in such a way that the rainwater tank is able to service water requirement to maximum period of time. This can be done by limiting the amount of use of water demand per person.

Suppose in this method, the amount of water supplied to individuals is limited which is equal to say, 135 lt/day per capita water demand.

Again, approx. no. of people residing = 200

Then, Total amount of water consumption per day = 200 x 0.135 = 27 m^3/day

Total no. of days we can utilize preserved water = stored water/water demand

Volume of water stored in tank was taken approx. = 3600 m^3

Hence finally, no of days = 3600/27 = 133 days (or 4.44 months)

For long term storage of preserved water in good condition, preserving chemical should be added.

5.1.1. Rapid Depletion Method (RDM):

In Rapid Depletion method, there is no restriction on the use of harvested rainwater by consumer. Consumer is allowed to use the preserved rain water up to their maximum requirement, resulting in less number of days of utilization of preserved water. The rainwater tank in this method is considered to be only source of water for the consumer, and alternate source of water has to be used till next rains, if it runs dries.

For example if we assume per capita water demand = 180 lt/day = 0.15 m^3 /day

Total amount of water consumption per day = 200 x 0.18= 36m^3/day

Total no. of days, preserved water can be utilize = stored water/water demand = 3600/36 = 100 days (3.33 months)

Hence, finally it is observed that, if the amount of water stored is equal to 3600 m^3, then applying

1. RDM, consumer can only utilize the preserved stored water for about 100 days

   (3.33 months),

2. Where as in RM, preserved stored water can be utilized for a period of 133 days

   (4.44 months).

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6. OPTIMISTIC DETERMINATION OF SIZE & TYPE OF TANKS:

6.1. General:

Just to start with, now let us consider only residential apartments (MULTI-STORIED) and proceed with calculation in details. And all the calculation in the later part of this project will be adopted for rest of the buildings in urban areas. A residential apartment which is multi-storied in the Hyderabad City is the present study area. This building presently has capacity of 300 individuals. The total rooftop area of the Building available for the rainwater harvesting is 2,609m^2. The cumulative runoff that can be captured from the paved area is calculated using Hyderabad Meteorological Department. The cumulative rainfall runoff at the end of the year is calculated to be 2348m^3. The tank capacity can be estimated to be a lower value accounting for the continuous consumption going on during period of rainfall.

6.2. Computation of Volume of Runoff per year:

Volume of water Received (m^3) = Area of Catchment X Amount of Rainfall

Total roof area of Residential Building = 3,600 m^2

Average annual rainfall at Hyderabad = 900mm/year = 0.9 m^3 /year

Total volume of surface runoff water suppose to be collected = 3,600 x 0.9 = 3240 m^3/year

6.3. Optimum Dimensions of Tank:

For a residential apartment (multi-storied),

total amount of water collected in one year is equal to the size of the tank = 2600 m^3

- Taking height of tank = 4m
- Area of the base = 2600/4 = 650 m^2
- We can take square base each of side = 25.5 m or rectangular base as per land availability. So our tank will be of dimensions 4 x 25.5 m x 25.5 m (taking square tank) which is not economical.
- As water is stored on monthly basis, S ize of the tank will be equal to the excess amount of water left over after consumption. Hence, mostly excess amount of water assumed to be collected during the period of maximum rainfall – June, July, August and September.
- Assuming amount of water consumption per month = 200 x 0.1 x 30 = 600 m^3
- Amount of water collected during July and August = 622.08 + 828.36

  = 1450.44 m^3
- And, amount of water consumed during this two month = 2 X 600 = 1200 m^3
- Total amount of water to be stored = Size of tank = (1450.44-1200) m^3 = 250.44m^3
- Fixing the height of tank to be 4m,
- Area of the base = 250.44 / 4 = 62.61 m^2
- So, as per suitability base can be taken as square of size 7.9 x 7.9 m or rectangular. Say, 8 x 8

Hence, now tank will be of dimension 4 x 8 x 8 m which is economical and feasible. Thus this is the optimum dimension of the tank. Similarly, the above procedure repeated to other all buildings in the Hyderabad and rainwater harvesting capacities calculated.

6.4 Design of Filteration System:

Total population of the apartment = 200

Average demand = 135 x 200 = 27000 lt/day

Maximum demand = 27000 x 1.5 = 40500 lt/day

Considering rate of flow as 150 lt/hr

Rate of filtration = 150 x 24 = 3600 lt/m^2/day

Therefore surface area of filtration required is

S.A. = Maximum Daily Demand / Rate of Filtration

= 40500/3600 = 11.25m^2

Surface area of filtration unit = 11.25 m^2

6.4.1. Designing of Slow Sand Filters:

Length of slow sand filter is as 2.5 times than its width

AREA = L X B

L = 2.5 B

Area = 2.5 B x B = 11.25

B = 2.12 m

Then L = 2.5 B =5.3m.

Dimensions for Slow Sand Filtration Tank:

L X B = 5.3m X 2.12m

6.4.1. Designing of Rapid Gravity Filters:

Length is 1.5 times more than width

L = 1.5 B

$1.5B^2$ = 11.25

B = 2.73m

L = 2.73 X 1.5 = 4.09m

Dimensions:

L X B = 4.09m X 2.73m

7. DETAILED COST ESTIMATION OF TANK:

Finally cost of entire project play a crucial role in any type of project. Before implementing the project, it is highly necessary for the engineers to check project, whether it is economical or not. Hence, the detail cost estimation should be done.

Tank shall be of first class brickwork in 1:4 cement mortar foundations and floor shall be of 1:3:6 cement concrete. Inside of septic tank shall be finished with 12mm cement plaster and floor shall be finished with 20mm cement plaster with 1:3 mortar mixed with standard water proofing compound. Upper and lower portion of soak-pit shall be of second class brickwork in 1:6 cement mortars and middle portion shall be of dry brickwork. Wall thickness is about 30cm. Roof covering slabs shall be precast R.C.C. The length of the connecting pipe from latrine seat may be taken as 3 meters. And suitable rates are assumed. Given below the detail cost estimation for construction of Rain Water Harvesting Tank with Standard Dimensions (4 x 5 x 12):

Table 2. Detail Estimation:

Sl. No.	Particular	No.	Length(m)	Breadth(m)	Height/depth(m)	Quantity(m^3)
1	earth work in excavation	1	12.80	5.80	4.3	319.232
2	Cement concrete 1:3:6 in foundation	1	12.80	5.80	0.3	22.27
3	I class brick work in 1:4 cement mortar					
	i. Long wall	2	12.60	0.30	4	30.24
	II.short wall	2	5.0	0.30	4	12
					Total	42.24
4	R.C.C work for slab cover	1	12.60	5.60	0.20	14.112
5	12mm plastering inside with 1:2 cement mortar					
	i.long wall	2	12	-	4	96
	ii.short wall	2	5	-	4	40
					Total (Rs)	**136**

Table 3. Abstract of Estimated Cost:

Sl no	Particular	Quantity	Rate	Cost(Rs)
1	Earthwork in excavation	319.232 m^3	100 Rs/m^3	31923.2
2	Cement concrete 1:3:6 in foundation with brick ballast	22.27 m^3	2700 Rs/m^3	60129
3	I class brickwork 1:3 cement mortar	42.24 m^3	3000 Rs/m^3	126720
4	R.C.C work for slab cover	14.112 m^3	2700 Rs/m^3	38102.4
5	12mm plastering with 1:2 cement mortar	136 m^3	2700 Rs/m^3	367200
			Total	624074.6
6	Contingency + work charges establishment	(3% + 2 % = 5 %)	--	31203.73
7	Engineering profit	10%	--	62407.46
			Grand Total	**717685.80**

Hence, after studying the present market value of material required for constructing the entire tank and using it while calculating during costing and estimation of tank. After all several steps, the total cost of tank was came out to be Rs. 7,17,685.80. This step was applied to all other building for determining the final cost price of the tank.

8. RESULTS & DISCUSSION:

Table 4. Monthly Rain fall and Discharge Values

Month	Precipitation (mm)	Discharge (m^3)
January	13.4	48.24
February	12.6	45.36
March	23.5	84.6
April	22.0	79.20
May	40.3	145.08
June	113.8	409.68
July	172.8	622.08
August	230.1	828.36
September	125.3	451.08
October	102.4	368.64
November	43	154.80
December	6.6	23.76
TOTAL	**905.8**	**3260.88**

International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 1, Issue 2, February 2014)

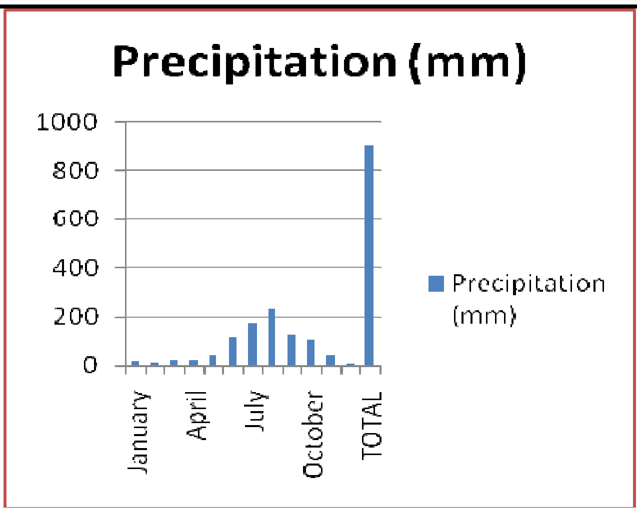

Fig1: Showing Amount of Precipitation throughout the year

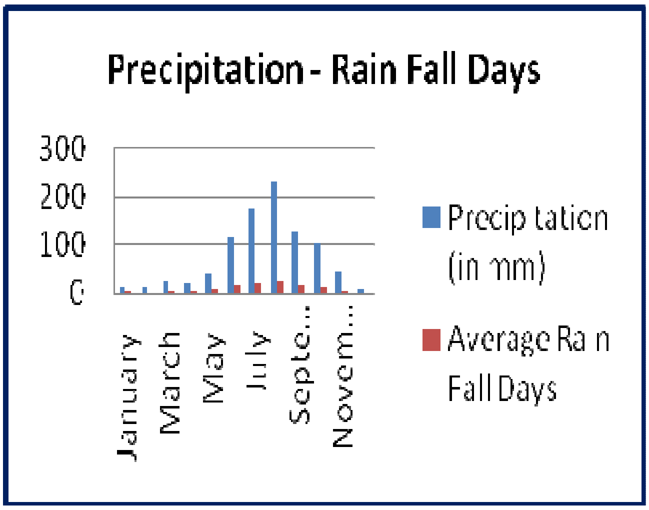

Fig2: Showing Amount of Precipitation – No. of Days of Rain Fall

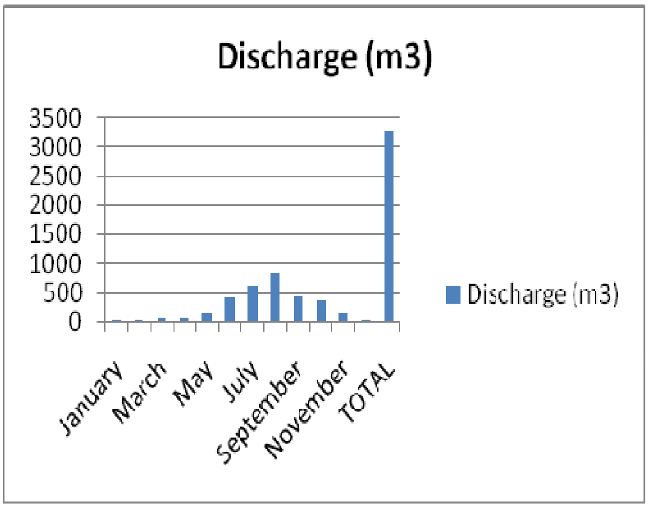

Fig3: Showing volume of water collected from precipitation Through out the year

DIMENSIONS OF TANK & COST OF CONSTRUCTION

Depending upon the hydrological analysis of runoff per month for different building, the size of the underground tank was designed. As the design of the Sample tank i.e. Residential Apartment (Multi-storied) was carried out in the section 6 in detail. Hence, the same procedure is being followed for all other buildings in a similar manner to calculate the optimum dimension of tank s.

The dimension of the tank was so chosen that depth of the tank should not be too deep, which will create trouble like high cost of excavation, high cost of construction of retaining wall as pressure increases at the rate of square of the height and finally there will be great difficulty in maintenance. Hence the depth of the tank at max, was fixed to 5 -6 m below the ground level. Again, underground tank was chosen for best possible utilization of land by building some playground or cycle stand above the tank.

Complete estimation and costing of Residential Apartment (Multi-storied) was done in the section 7 in the table 2 & 3. The same procedure was just repeated neglecting any variation in thickness (30cm) of the tank for different tank size for ease of calculation and comparisons between them.

For designing purpose, following data were assumed to be constant. This value can be changed later on depending upon different situation. Hence, No. of person consuming water from any Residential Apartment (Multi-storied) was assumed to be 200.

Annual average rainfall was assumed to be 900 mm.

The rate of consumption, here was fixed to be 100liter/day.

Standard Dimensions of Tank: 4 x 5 x 12 m

Optimum Dimensions of Tank: 4 x 7.9 x 7.9 m

9. CONCLUSION

This paper dealt with all aspect of improving the water scarcity problem by implementing ancient old technique of rainwater Harvesting. Two alternatives have been suggested for tank design, which takes separate approaches towards the consumption of harvested rainwater. These results are given clearly in the table no.7. Hence from this table, we can draw out a conclusion that a huge amount of water got collected from the rooftop surfaces of all the entire buildings. This reservoir should have to build for the storage of 3600 m^3 of water.

Hence this tank has huge capacity of getting rainwater and on proper storage, this tank can supply almost throughout the year for about 200 consumers having a consuming rate of 100liter/day as calculated by rational

International Journal of Ethics in Engineering & Management Education
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depletion method. The water has almost the potential amount of tank

Reservoir capacity (m^3)	No. of days of potential by	No. of days of potential by
3600	133	100

It is concluded that RCC tank which is to be constructed should be an underground one, so that upper surface of the tank can be utilized economically for any land purpose such as playground or cycle stands or any such small structure.

Cost analysis has been done for all the tanks. And it was concluded that cost of construction was not so high, if it is compared with problems which are faced by the students and staffs inside the campus due to huge water scarcity. The other component of the harvesting systems such as Guttering, First-F lush, and Filtration mechanism have also been reviewed and designed for the hostels and all other building in details.

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