Rainwater Harvesting Options: Quantitative Overview

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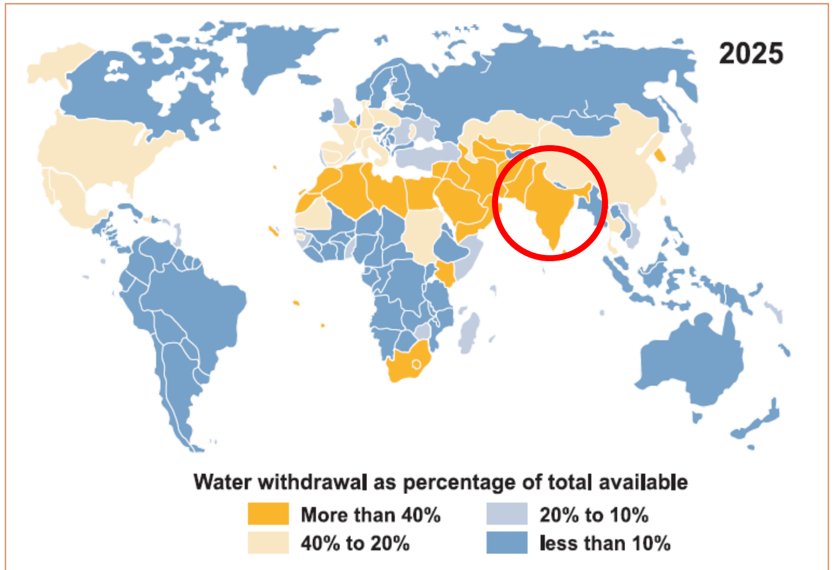
Acknowledgement: Himanshu Sail

Background

- Many regions around the world including the middle east, northern China, India, North Africa, and the middle and western regions of the United States lack water and are water impoverished regions
- The shortage of water lies in more than **80 countries** across the world and it is predicted that by **2025,** more than **1.8 billion** people will be living in countries or regions with absolute water scarcity and two thirds of the world's population will be living under water stressed conditions.
- Rainwater harvesting is a well-established concept in India as well as in various countries across the globe. The methods for doing the same have differed over time and place but its importance and relevance has only increased with time. Though the average rain fall/unit area/person is significant, to avoid a water crisis anytime in the near future, it is of utmost importance that we start thinking of water as a finite resource and try to conserve every drop from every possible source



by the year 2025, two third of the world population may be subjected to water scarcity

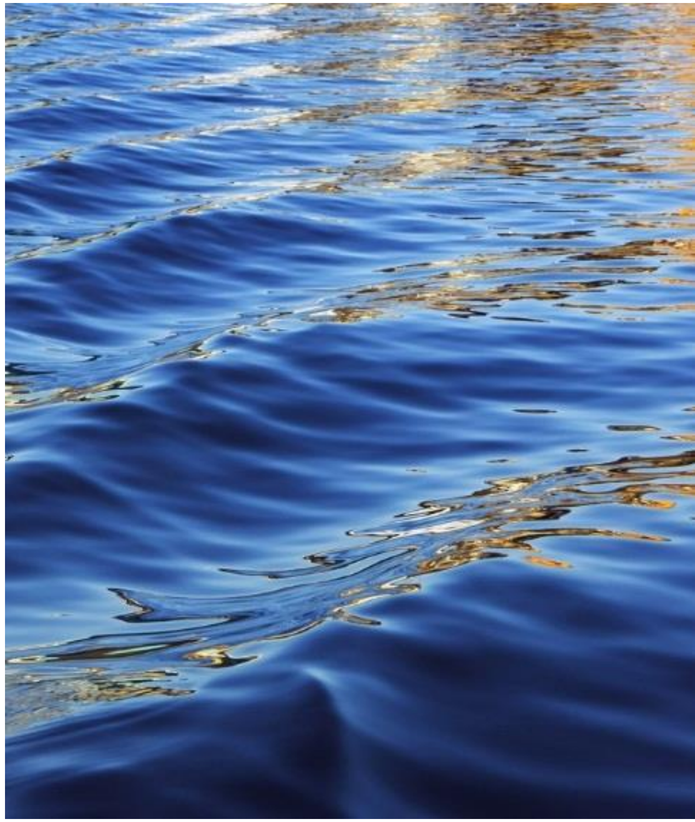
Introduction

- The basic principle of rainwater harvesting is to capture the precipitation falling in one area and then store it in another, thereby increasing the amount of water available in future for all. The rainwater harvesting system consists of a catchment or collection area, the runoff conveyance system, a storage component and an application area.

- **Some definitions**

Catchment or Collection Area	Conveyance system	Storage component	Application or Cropping Area
• It is the region where the rainwater is harvested. • The size of the catchment area can vary greatly depending upon the type of the systems	• The runoff flows through gutters, grills, channels and gullies and is directed to cultivated fields which are called as the conveyance systems	• Soil itself acts as an excellent vessel to store water. • Other options include jars, ponds or reservoirs, underground cisterns or as groundwater near surface aquifers	• This is the area where the harvested water is actually put into use. • It can be for domestic uses like drinking and household use, for livestock consumption or for irrigating farms or fields (almost 70% of total consumption).

Micro Catchment Rainwater Harvesting



- In this method, the surface runoff from a small catchment area is collected and stored in the root zone of a neighboring infiltration basin.

- The catchment area is small, usually between **20m² to 500m²**. The ratio of the catchment area to that of cropping area is called as catchment to cropping ratio **(CCR) and generally varies between 2:1 to 10:1.**

- MicroWH is appropriate for semi-parched to dry regions with high precipitation fluctuation inside seasons. They can be developed on various inclines, including almost level fields any place there is overland stream to catch.

- Soils should be sufficiently profound to develop openings, pits and to store the gathered water.

Negarim

- Negarim micro catchments are primarily utilized in arid and semi-arid regions. The diamond shape catchment area consists of an infiltration pit at its lowest corner in which the runoff is stored.
- The annual rainfall of the region can be anywhere between **150 mm to 700 mm** and the soil must be at least 1.5 m deep to ensure that roots are developed adequately and sufficient water can be stored.
- The bund height is decided by the size of the micro catchment and the prevailing ground slope. As a rule of thumb, **the bund height should be at least 25 cm** to avoid the risk of over topping and subsequent damage.
- Assuming a rainfall of 700 mm, a typical catchment area of 100 m^2 and a run off coefficient of 0.8, **56 m^3 of water can be harvested from the system per year**

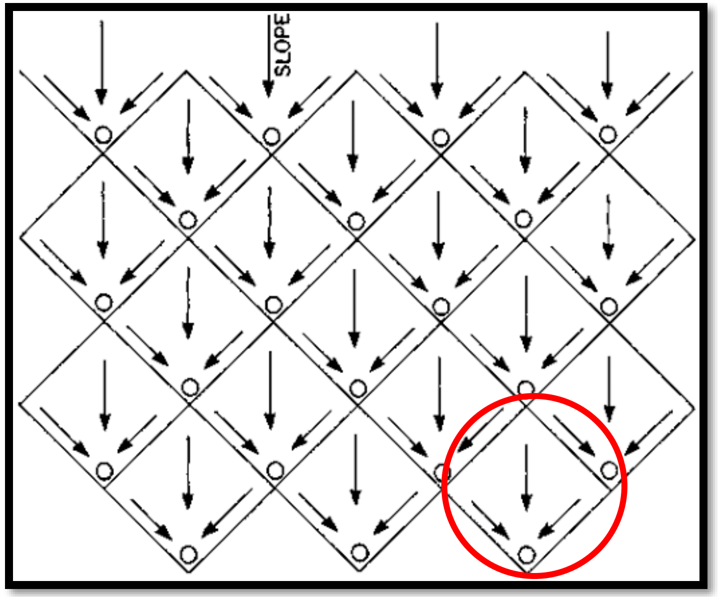
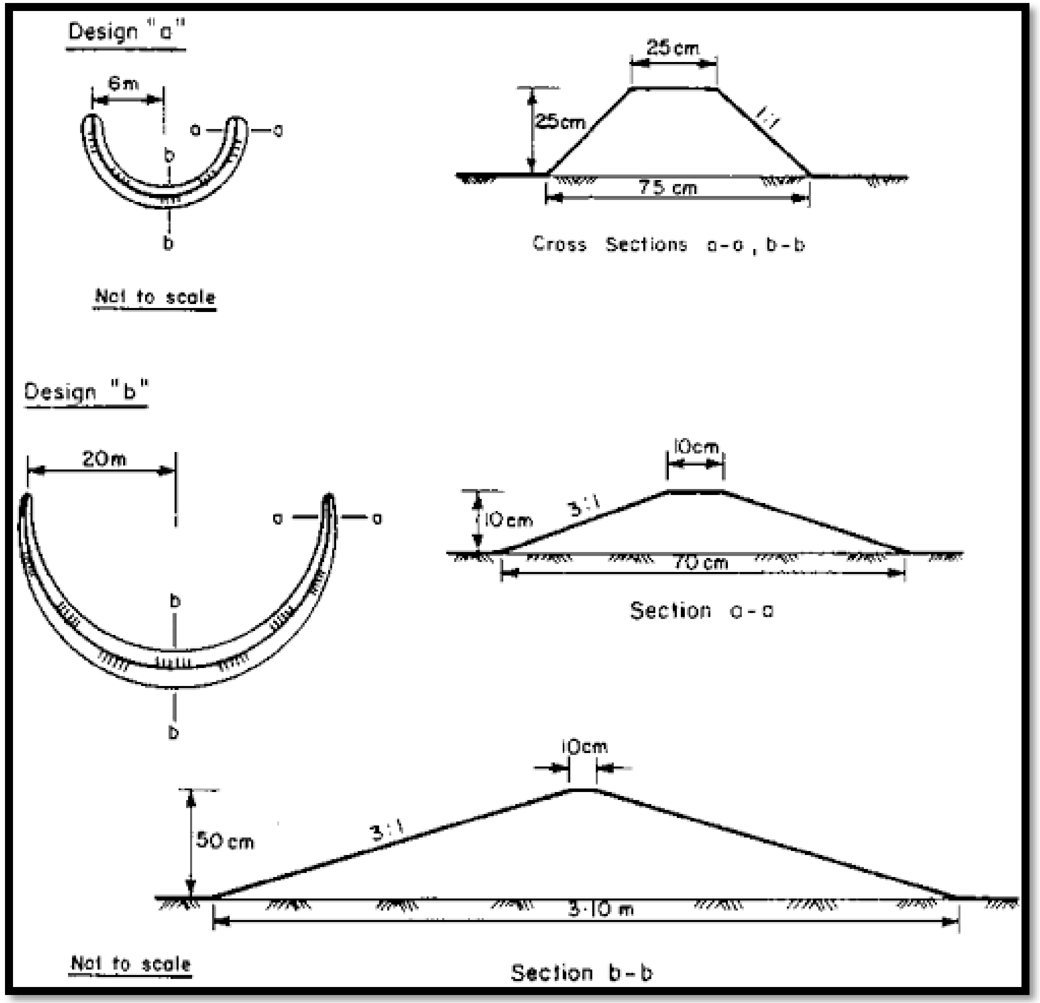


Table below gives the recommended bund height (cm) as a function of slope and size of the catchment.

Size of micro catchment in m²	Slope of ground (%)			
	2%	**3%**	**4%**	**5%**
3x3	25	25	25	25
4x4	25	25	25	30
5x5	25	25	30	35
6x6	25	25	35	45
8x8	25	35	45	55
10x12	30	45	55	not recommended
12x12	35	50	not recommended	
15x15	45	not recommended		

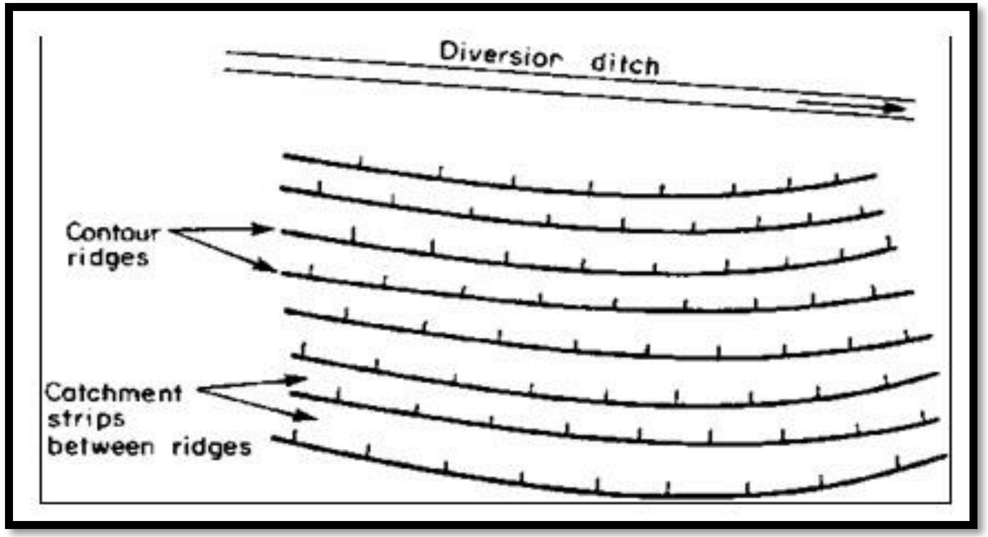
Semi-circular Bunds

- In this technique, semi-circular embankments are built with the tips of the bunds on the contour. They are ideal for regions receiving rainfall between **200 mm to 750 mm per annum**.
- The **maximum slope of the land allowed is 20%,** the soil should be substantially deep and salinity should be low.
- The catchment area to cropping area **ratio CCR can be between 3:1 to 5:1. The ideal ratio is 4:1.**
- The radii of the bunds in design “a” is 6 m while 20 m for those in design “b”. Both the designs consist of runoff producing catchments constructed by staggered lines between structures.
- There needs to be a provision of a **diversion ditch** in case of damage due to heavy rainstorms. Generally, a dense network of perennial grasses prevents any erosion or damage to bund.



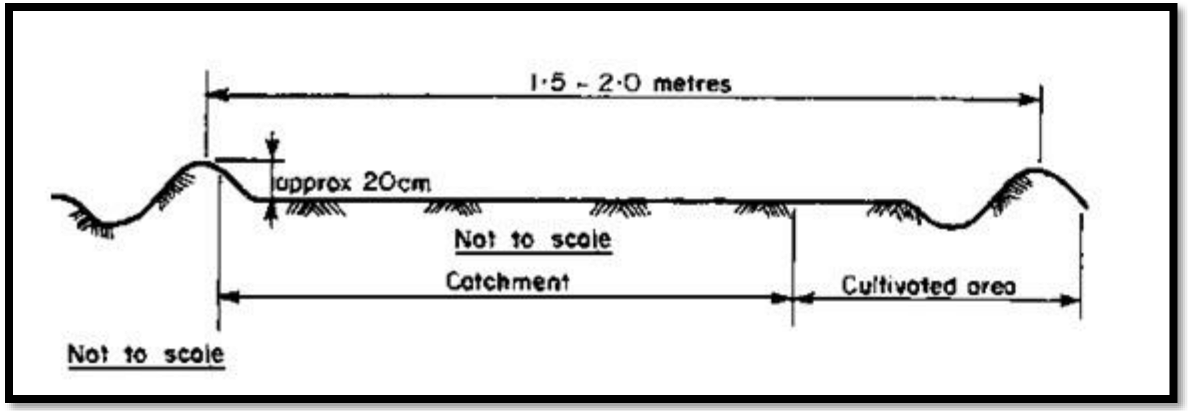
Contour Ridges

- Contour ridges are ideal for areas that receive a mean annual **rainfall between 350 mm to 750 mm per annum**. Regions with rills and undulations are not amenable for contour ridges.
- The ridges are formed from the soil that is dugout from the furrow excavation. The runoff is collected from the catchment stream between the ridges in the furrow.
- The ratio of the catchment area and cropping area **(CCR) is 2 with a catchment strip of 1 m and a cultivated strip of 0.5 m.**
- Generally, a distance of **1.5 m is maintained between the ridges**. If a distance of 2 m is maintained, CCR of 3 is also possible.
- If the length of the catchment is very small, the loss of water from the system can be prevented completely, making it **extremely efficient.**



Design of the Ridge

- The ridges should be sufficiently high so that overtopping by runoff can be prevented. Since, only a small strip between the ridges is used to harvest the runoff, a **height between 15-20 cm is generally sufficient.** The height may have to be increased if the bunds are spaced at a distance of more than 2 m



- The table gives the quantities of earthwork required as a function of the contour ridge spacing and height. **Wherever a ditch is required, 62.5 m^3 of earthwork needs to be added per 100 m length.**

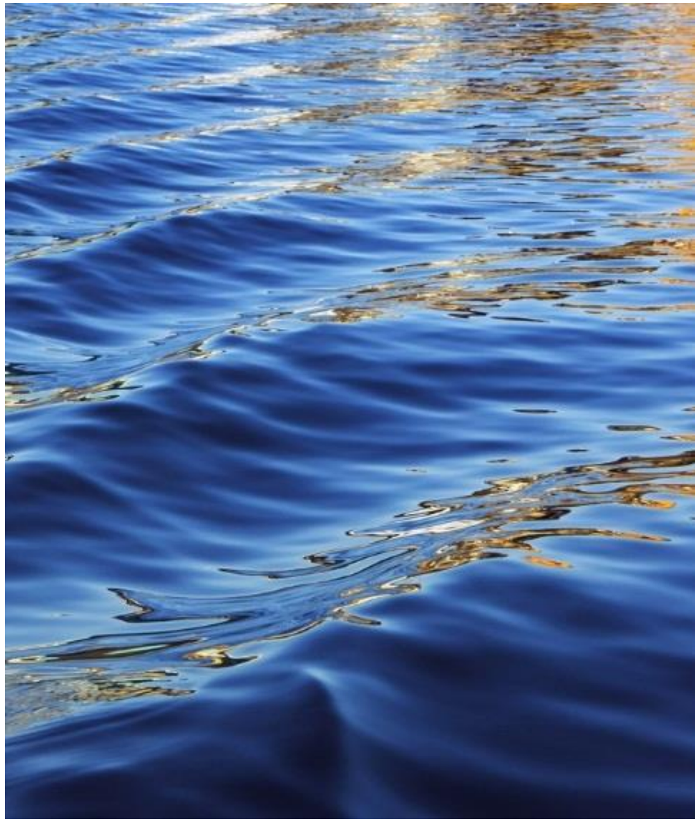
Ridge spacing (m)	Ridge & Tie height (cm)	Earthworks per ha (m^3)
1.5	15	270
1.5	20	480
2.0	20	360

Summary of various techniques

Apart from the, there are various other micro catchment strategies which are practiced across the globe. Some common examples include Pitting type catchments, Meskat type ridges, contour bench terraces and Vellarani type or fully mechanized systems. They are typically compared on the basis of parameters such as Catchment area (CA), Cropping area (CR), Catchment to Cropping Ratio (CCR), percentage slope (SL), Precipitation (PREC) per square meter in one hour (mm/a).

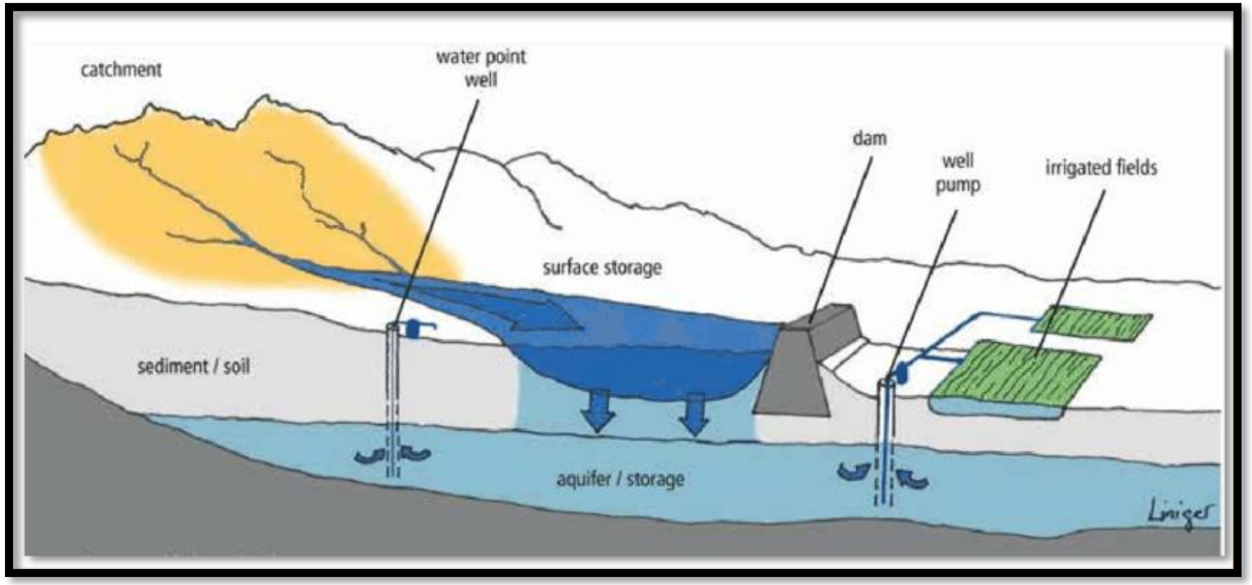
Sr. No	Technique	Catchment Area (CA) in m^2	Cropping area (CR) in m^2	CCR	PREC (mm/a)	SL (%)
1	Negarim	3 - 250	1 - 10	3:1 - 25:1	150 - 700	1 - 20
2	Pitting	0.25	0.08	3:1	350 - 600	0 - 5
3	Contour ridges	100	50	2:1	350 - 750	5 - 25
4	Semi-circular hoops; Triangular bunds	24 - 226	6 - 57	4:1	200 - 750	2 - 20
5	Meskat Type Ridges	500	250	2:1	200 - 600	2 - 15
6	Vallerani Type Ridges	15	2.5	6:1	100 - 600	20 - 50
7	Contour bench terraces	2 - 16	2 - 8	1:1 - 8:1	100 - 600	20 - 50
8	Eyebrow terraces or Hillslope micro catchments	5 - 50	1 - 5	3:1 - 20:1	100 - 600	1 - 50

Macro Catchment Rainwater Harvesting



- In the macro catchment rainwater harvesting system, the catchment area can range from **1000 m^2 – 20E+07 m^2**. The runoff is collected from roads, open rangelands, hillsides, and cultivated and uncultivated natural slopes.

- The ratio of the catchment area to the cropping area can vary between **10:1 to 100:1.**



- The water is either stored in the soil by diverting it to cultivated fields or can be channeled through overland to specifically designed storage facilities. If the concentrated runoff is redirected to fields, the application territory is indistinguishable with the catchment zone, as plants can directly utilize the collected soil water.

- Some of the most common technologies are: hillside runoff / conduit systems; large semi-circular or trapezoidal bunds (earth or stone); road runoff systems and open surface water storage in dams, ponds and pans; groundwater dams (subsurface, sand and percolation dams); above- or below-ground tanks (cisterns); horizontal and injection wells.

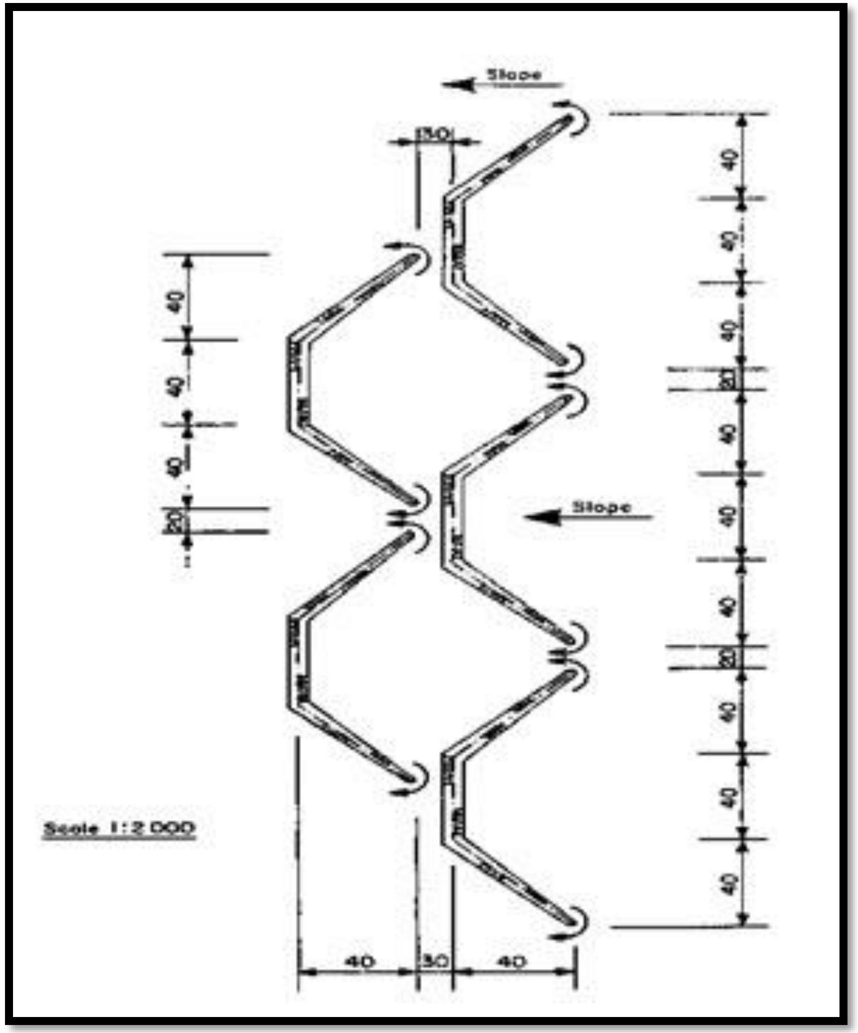
Trapezoidal Bunds

- The system consists of a base bund, which is usually connected to two side bunds or **wing walls at an angle of 135°** . The technique is suitable for areas that receive an annual rainfall between **250-500 mm.**

- Generally, a distance of **20 cm** is maintained between the bunds in the adjacent line and a spacing of **30 cm** is maintained between the tips of the lower row and the base bunds of the upper row.

- Trapezoidal bunds are generally limited to two rows, since the third or the fourth row receives very less runoff. At the base of the bunds, a maximum floodwater depth of **40 cm** is maintained.

- When the gradient becomes steeper, the **efficiency of the model decreases with increasing slope** due to increased earthworks requirement per unit cultivated area.



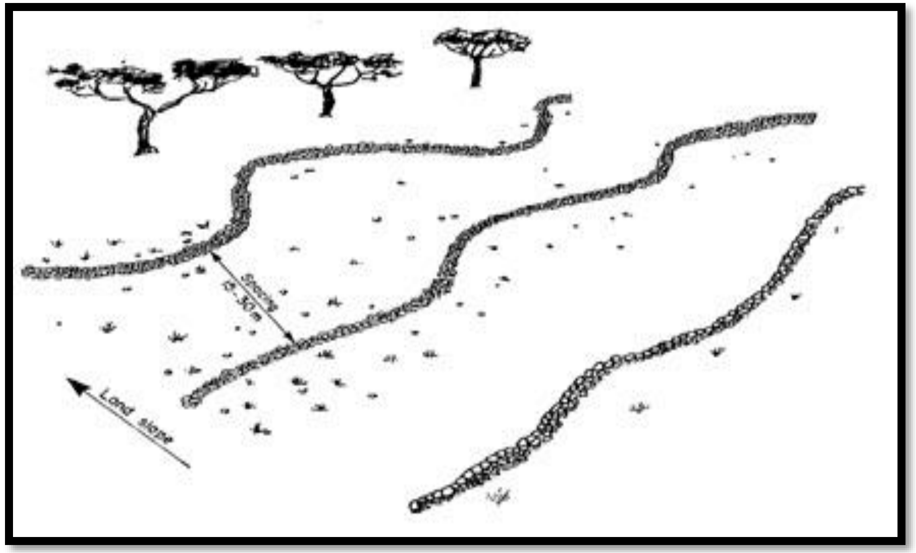
Contour Stone Bunds

- The stone bunds are recommended in regions that receive an annual rainfall between **200 mm to 750 mm.** The soil should be amenable to crop production and the slope of the land should be not more than **2%.**

- The contours are built across the fields or the grazing lands. The bunds are spaced at a distance of **15 m to 30 m** depending upon the amount of labor and stone available.

- The design of bund is simple with a **base width of 35-40 cm** and a minimum **bund height of 25 cm.** The undermining by runoff is prevented by setting the bund in a shallow trench of 5-10 cm depth.

- If the slope is between **1-2%**, bund spacing of **15 m** is sufficient while for slopes below **1%**, a spacing of **20 m** is recommended.



Sr. No	Technique	Catchment Area (CA) in m²	Cropping area (CR) in m²	CCR	PREC (mm/a)	SL (%)	SLCA (%)	SLCR (%)
1	Contour stone bunds	extreme variations			200-750	0-2%	-	-
2	Large semi-circular hoops	750 – 10,000	50-350	15:1 - 40:1	200-400	1-10	-	-
3	Trapezoidal bunds	1000 – 10,000	100	10:1 - 100:1	250-500	1-10	-	-
4	Hillside conduit systems	$10 - 10^7$	$1-10^5$	10:1 - 100:1	100 - 600	-	> 10	0-10
5	Liman Terraces	20,000- 200,000	1000-5000	20:1 - 100:1	100-300	1-10	-	-
6	Cultivated reservoirs	1000 – 10,000	100-200	10:1 - 100:1	150-600	-	>10	0-10

Case Study: Soan Catchments

- An economic analysis and viability check were performed for the Soan catchment in the north-western Himalayas. The estimated value of run off (180 mm) was multiplied with the catchment area to compute the volume stored by every sub-catchment.

- The volumes of all the sub-catchments were summed up to get the total volume. The life of the catchments and the overall structures is between 25-40 years. For the purpose of this case study, a minimum life of 25 years was assumed. Evaporative losses and seepage losses are assumed to be 5% and 20% respectively.

Parameter	Area (km^2)	WHCA (ha)	Water to be stored (Ml)	Evaporation loss (Ml)	Seepage loss (Ml)	NAW (Ml)
Average	37.7	527.1	957	138	189.7	629.3
Maximum	65	900	1620	236	324	1060
Minimum	18	260	468	68	94	306
S.D.	12.7	183	331.7	47.9	65.9	217.9
Av. Dev.	10.1	145.4	261.2	38	52.4	170.8
Total	1204	16700	**30060**	4371	6011	19678

Revenue

Crop	Increased yield ($t\ ha^{-1}$)	Procurement price ($\$\ t^{-1}$)	Area (ha)	Cost of fertilizers and insecticides ($\$\ ha^{-1}$)	Increased Revenue ($)
Maize	0.5	96	19680	28	393,000
Wheat	0.5	136	19680	28	787,000
	1.0	136	19680	28	2,125,440
	1.5	136	19680	28	3,463,680

- It was assumed that the yield of Maize will increase by 0.5t ha^{-1} and three possibilities of 0.5, 1.0 and 1.5t ha-1 were considered for Wheat.
- By implementing the water harvesting plan, the total increase in the annual income would be somewhere between $1,180,800 to $3,857,280ie about INR 5000 to 15000 per ha

Costs

The major costs for the projects is to build reservoirs to store the harvested water.

Life of reservoir (years)	Size of the reservoir (Ml)	Cost of construction ($ Ml-¹)	Capital cost of construction	Present value of Lifetime maintenance ($)	Present value of Total Cost (Construction + Maintenance) in $	Present value of Total Cost ($ ha-¹)
25	7.5 (small)	640	19,238,400	9,604,525	28,842,925	1466
	25 (medium)	560	16,833,600	8,396,160	25,229,760	1282
	75 (large)	480	14,428,800	7,199,520	21,628,320	1099
40	7.5 (small)	640	19,238,400	10,340,640	29,579,040	1503
	25 (medium)	560	16,833,600	9,045,600	25,879,200	1315
	75 (large)	480	14,428,800	7,770,240	22,199,040	1128

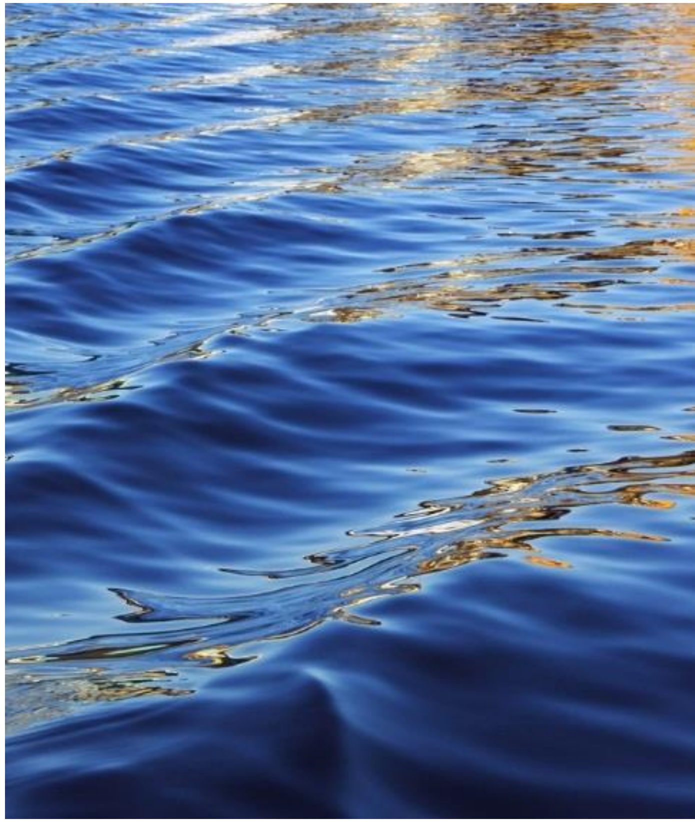
Life of structure (years)	Crop return	Present value of additional net revenue ($ ha⁻¹)	Size of reservoir	Present value of construction and maintenance cost ($ ha⁻¹)	Benefit/cost ratio
25	M0.5 + W0.5	600	Small	1466	0.41
	M0.5 + W1.0	1000			0.68
	M0.5 + W1.5	1400			0.96
	M0.5 + W0.5	600	Medium	1282	0.47
	M0.5 + W1.0	1000			0.78
	M0.5 + W1.5	1400			1.09
	M0.5 + W0.5	600	Large	1099	0.54
	M0.5 + W1.0	1000			0.91
	M0.5 + W1.5	1400			1.27
40	M0.5 + W0.5	645	Small	1503	0.43
	M0.5 + W1.0	1075			0.72
	M0.5 + W1.5	1505			1.00
	M0.5 + W0.5	645	Medium	1315	0.49
	M0.5 + W1.0	1075			0.82
	M0.5 + W1.5	1505			1.14
	M0.5 + W0.5	645	Large	1128	0.57
	M0.5 + W1.0	1075			0.95
	M0.5 + W1.5	1505			1.33

M5 and W5, W10, W15 are additional increase in yield with 0.5 t ha⁻¹ for maize and 0.5, 1.0, 1.5 t ha⁻¹ for wheat, respectively

Conclusion

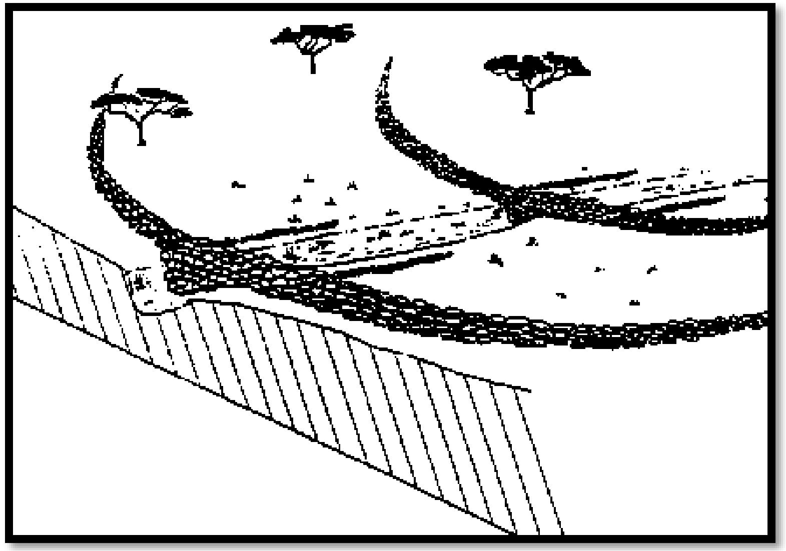
- It is apparent that the total cost for implementing the proposed water management plan considering various alternatives varies from **15.15– 20.20 million USD**, whereas the total additional net annual income from the catchment considering the minimum increase in grain yield of wheat and maize each to the tune of 0.5 t ha-1 comes to be $ 1,180,800.
- Thus, even if the minimum life of the structure (25 years) and minimum additional increase in grain yield of maize and wheat (each 1.0 t ha^{-1}) are considered, the project cost can be recovered in **6 to 8 cropping cycles (3 to 4 years assuming two cycles per year).**
- However, the project cost is likely to be recovered in **2 years** if only large structures are constructed and additional increase in yield is 1.5 t ha^{-1} for wheat.

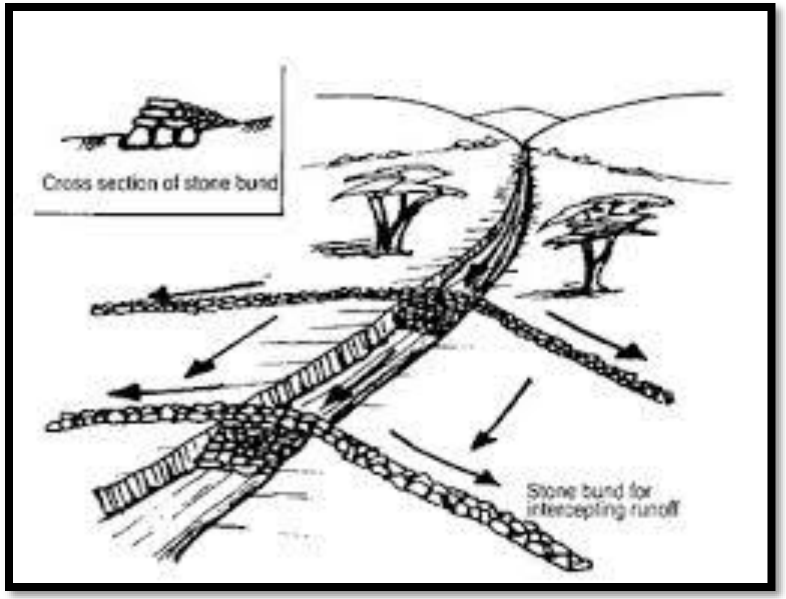
Floodwater Harvesting



Permeable Rock Dams

- This floodwater harvesting technique consists of long, low structures that can control gully erosion while depositing silt and improving plant growth by spreading and retaining the runoff.
- The dam wall, which is about **70 cm high**, is the most crucial part of the construction. A **maximum height of 2 m** can be achieved in the central portion of the dam.
- In the widest of the valley beds, the dam walls or the spreader can extent up to **1000 m**. However, the lengths normally range between **50 to 300 m**.
- The design of the dam wall is such that the large boulders are used to form the skeleton and the smaller ones are packed in the middle like a sandwich.
- The ratio of the horizontal to vertical slopes of the wings is between **3:1 to 2:1** on the downstream side and **2:1 to 1:1** on the upstream side.





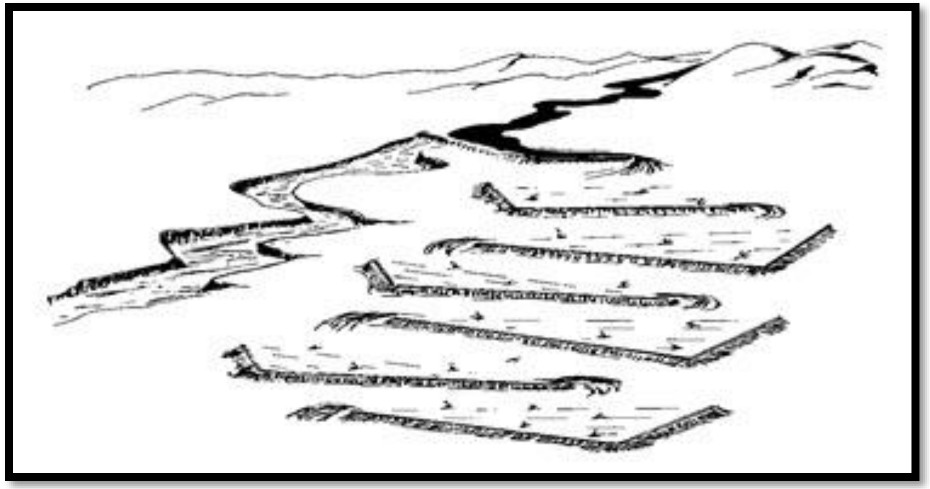
Water Spreading Bunds

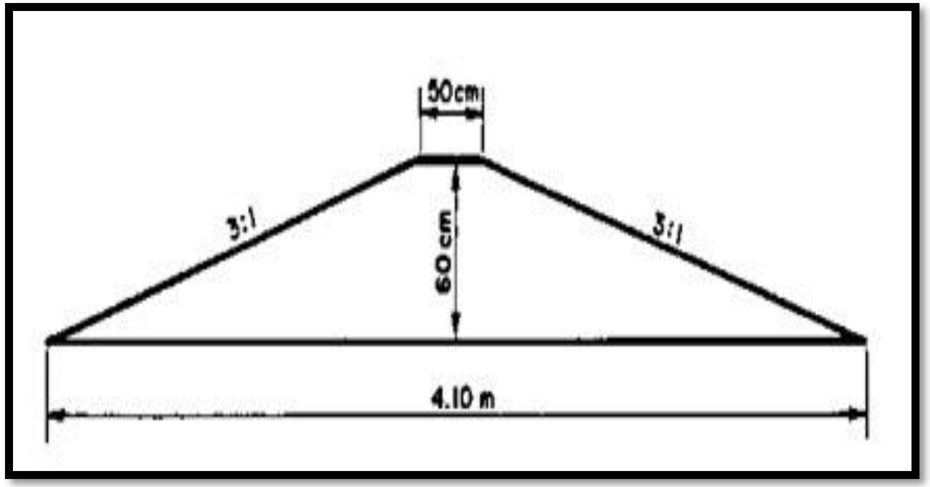
- This technique is recommended in hyper arid to arid regions that receive a mean annual rainfall between **100 mm to 350 mm**. As the floodwater is spread and not impounded, it is not practically possible to calculate the catchment to cropping area ratio.

- The design of the bund depends largely on the land slope. It can be designed in the following manner:

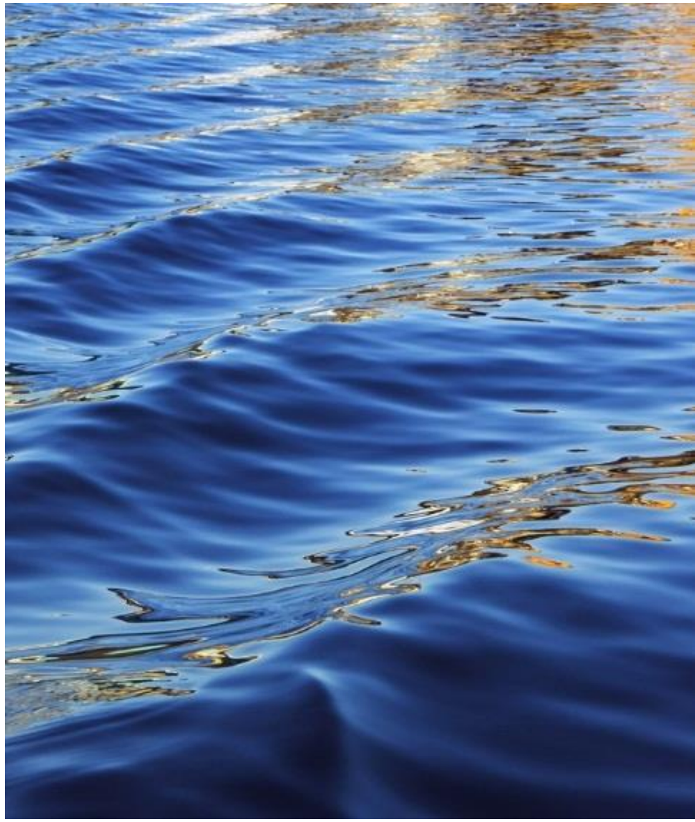
1. **Land slope less than 0.5% :** Straight bunds are positioned **50 m** apart. The dimensions recommended for the bund are **4.1 m base** width, **50 cm top** width and **60 cm of height**. A maximum length of 100 m is recommended over which stable side slopes of 3:1 can be maintained.

2. **Land slope between 0.5% to 1% :** The interception of the flow around the bund is carried out by constructing a short wing wall at angle of 135° to the upper end. The bunds are spaced depending on the slope of the land to check the flow further. The dimensions, cross section and base length is same as that recommended for lower slope bunds.



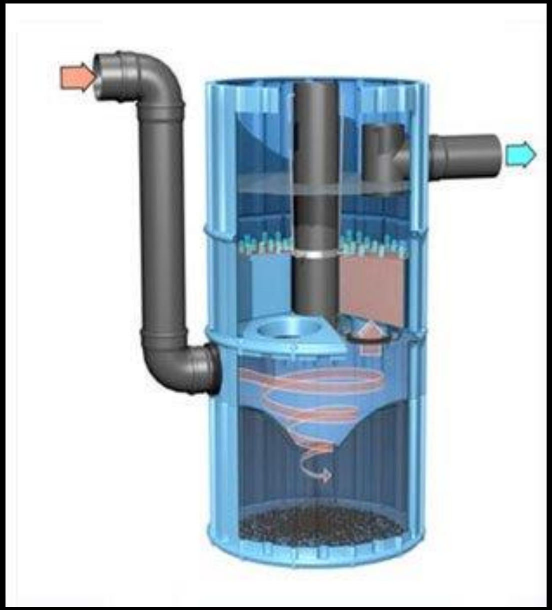


Rooftop and Courtyard Rainwater Harvesting



This is the most common method of rainwater harvesting as it provides water closest to home. This is the most common method of rainwater harvesting as it provides water closest to home. The house roofs and courtyard surfaces are used as catchment area that are used to collect the runoff. Following are some of the crucial components of the system:

- Roofing materials
- Conveyance systems
- Filtering systems
- Storage systems



Roofing Material

- Galvanized iron or aluminum sheets.
- Corrugated cement sheets.
- Asbestos sheets
- Tiles and slates
- Organic roof covering

Conveyance Systems

- V-shaped gutters
- Semi-circle gutters
- Square-sectioned gutters
- Wooden planks and bamboo gutters
- Extended gutters
- Separate open channel
- Downpipes
- Overflow pipes

Filtration Systems

- Coarse filters
- Fine filters
- First-flush diversion
- Fixed mass system
- Floating ball

Storage Systems

- Ferro-cement tank
- Ferro-cement water jars or jumbo jars (also known as pumpkin tank)
- Drum tanks / oil drums
- Brick tanks
- Pre-cast tanks
- Plastic tanks
- Underground tanks
- Partially below ground cement-lined tank

Case Study: RCWH in an Educational Institute

Consider an educational institute that is located in a town that receives an annual rainfall (H) of 800 mm. Presently, a part of water requirements are met from the municipal supply and remaining from a borewell. However, it is observed that the groundwater levels in the town have dropped considerably over years. The institute decides to recharge the depleted ground water by installing a rooftop and courtyard rainwater harvesting system.

Estimating the amount of water that can be conserved

- The **total catchment area** (CA) by combining the rooftops and courtyards of the institute is about **2250 m^2**.
- The perimeter of the institute building is about 350 m.
- The coefficient of runoff (R) is 0.8 i.e. 80% of the runoff can be successfully harvested.

$$Volume\ of\ water\ harvested\ (V) = CA * H * R = \mathbf{1440\ m^3}$$

Since the institute plans to recharge groundwater, the rainwater that has been collected needs to be directed to two soak pits. It was found that two soak pits, each with dimensions 6m x 6m x 1.5m would do the job. The cost of excavation at the rate of Rs 60 per m^3 would be:

$$Cost\ of\ excavation = 2 * (6 * 6 * 1.5) * 120 = \text{Rs } 12{,}960/-$$

Material	Cost (Rs)
Filling of 75 mm to 100 mm size aggregate	25,000
Filling of 15 mm to 25 mm size aggregate	2,500
Sand	15,000
Protection wall with perforation	15,000
Labour cost for filling material (Lump sum)	10,000

Accessories	Cost per metre (Rs)	Total cost (Rs)
PVC 6" pipe (200m)	200	40,000
PVC 4" pipe (120m)	180	21,600
Labour charges	Lump sum	40,000
PVC pipe accessories	Lump sum	20,000

The above tables give the costs of filling the pit and the plumbing costs

The total cost of implementing the project would be Rs 2,02,060.

Let us assume that 5% of initial investment needs to spent as annual maintenance of the system. The figure would be roughly Rs 10,000. So, the total of cost the project over a span of 10 years would be:

$$Total\ cost = Initial\ investment + (annual\ maintenance * life\ of\ the\ project)$$

$$Total\ cost = 2{,}02{,}060 + 1{,}00{,}000 = Rs\ 3{,}02{,}060$$

Total water that can be conserved in 10 years = 14400 m^3

$$Unit\ Cost\ of\ Water = \frac{Total\ cost}{Total\ water\ conserved} = \frac{Rs\ 3{,}02{,}060}{14400\ m^3}$$

The unit cost of water comes out to be Rs 21 per cubic metre or Rs 0.021 per litre.

Sources of Contamination

Pesticides, Organics and Pollen

- Physical transport of aerosol particles, volatilization into the atmosphere, and sometimes direct deposition onto roof surfaces can lead to rather substantial concentrations of pesticides, transformation products of the parent chemical, and other organic compounds in roof runoff.
- Organic substances can make their way into rainwater and roof runoff as well and are often remnants of fossil fuel combustion or industrial processes.
- Pollen is more a nuisance than a hazard when it comes to rainwater harvesting systems. It often makes its way into a system due to the fineness of the particles and the sheer abundance of pollen produced during the spring season.

Microbial Contamination

Microbial concentrations can vary based upon the contributing roof surface. Presence of fecal matter on roof surface or in gutters.

- Plant debris, organic matter, or dust on the roof surface or in gutters.
- Overhanging vegetation, presence of antenna or other perches for wildlife.
- Manual extraction of water from the tank.
- Defective access points in storage tank that allow for animals or insects to enter.

Methods of Treatment

First Flush	Debris Screens and Filters	UV, Chlorination and Ozone
• The first portion of a rainfall event produces the dirtiest runoff, as it washes off the material that has accumulated on a roof surface since the last rainfall. • Pre-storage first-flush diversion can significantly improve the quality of collected rainwater and its inclusion in the design of a rainwater collection system should depend upon the size of the system.	• Debris screens and filters can be used **between the roof surface and the storage tank** to prevent particulate matter (and contaminants adsorbed in particulate matter) from entering the tank • Filter should **not clog easily** and clogging should be easy to detect and rectify • Filters should not provide an entrance for additional contamination.	• A combination of **sand filtration and UV** light can be extremely effective in reducing bacteria concentrations in harvested rainwater. • The contact time between the water and ozone should be sufficient for adequate disinfection, and that ozone gas is released to a safe environment. • Chlorination is an inexpensive and effective form of disinfection. Concentrations of **0.4 to 0.5 mg/L** free chlorine are used for proper disinfection.

Thank You