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Harnessing conventional wisdom for rain water harvesting to mitigate the risks of climate change

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ABSTRACT

Rain water harvesting is the process of collection and storage of rain for various purposes. Rainwater harvesting continues to be the main source of water supply for potable and non-potable uses. Located in a hot and semi-arid region with water scarcity, the National Innovation Foundation - India (NIF) identified a need to conserve water for office use. Building upon the expertise and experience of Lok Mitra Trust in this field, NIF got built traditional, but unique type of rain water harvesting tanks also known as "Matka tank" at its headquarters in Gandhinagar, Gujarat. The unique features of the tank are its hemispherical shaped upper dome and saucer shaped bottom surface, which is being reported for the first time.The Matka tank for rain water harvesting may be considered as a sustainable technique to mitigate the water scarcity in the context of climate change.

Introduction

Linked to spiritualty and mythology in India, water is one of the most vital components for all life forms. It is impossible to imagine life on earth without water. But, indiscriminate use and inadequate water management has resulted in depletion of ground water resources, decline of ground water table and an ever increasing water stress. NITI Aayog (2018) has stated that India is facing the worst water crisis and about 600 million of India's population is already facing "high to extreme water stress". The report also observed that due to this water crisis, India may also witness a decline of 6% in the total GDP by 2030. Further, taking a call on the current scenario, on July 1, 2019, the Government of India launched the "Jal Shakti Abhiyan" identifying 1,592 blocks (1,186 over-exploited, 313 critical and 93 semi-critical) in 256 districts, facing acute water crisis with an aim of ensuring water conservation in these water stressed blocks with five interventions viz. a) water conservation and rainwater harvesting b) renovation of traditional and other water bodies/tanks c) reuse and recharge structures d) watershed development and e) intensive afforestation. Among all the interventions, rainwater harvesting is the simplest and cost effective technique to save water (Pala *et al.*, 2021). Rain Water Harvesting (RWH) is the process of collecting natural precipitation from prepared watersheds for beneficial use (Patil, 2019). It is pure in nature and a substantial source of income in many regions of the world. RWH can be used for agriculture and other utilities such as washing, toilet flushing, gardening, and so on.

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Water harvesting system is deep rooted in the science of ancient India. Archaeological evidence suggests that water harvesting systems have been use in the country for over 4000 years. Researchers have identified a total of 37 types of water conservation systems (figure 1) used in different parts of the country (Borthakur, 2009; Bhattacharya, 2015; Pradhan and Sahoo, 2019). Such local traditional practices are not found just in India, but also in other parts of the world as well. Every such practice has an associated knowledge system (about local geography, climate, soil, rainfall, flora etc.) and requires a specific skill set to assimilate this knowledge to reproduce the conservation systems. But in this era of increasing urbanization and technological development, we are consciously or unwittingly, not utilizing the traditional skills of non-craft artisans. The absence of demand for such and other traditional systems has made survival difficult for non-craft artisans, resulting in their abandoning of traditional skills in resulting in their abandoning of traditional skills in favor of more lucrative pursuits for a living. As a result, not only such skills are gradually vanishing but the associated knowledge systems are also getting depleted rapidly. Therefore, in order to conserve traditional skills and techniques, it is necessary to combine modern technological approaches with traditional knowledge to ensure the livelihood of grassroots innovators and traditional knowledge practitioners. The aim of this study is to disseminate information about an innovative rainwater management practice implemented by National Innovation Foundation-India (NIF), an autonomous body of the Department of Science and Technology, Government of India by leveraging the expertise and knowledge of people at the grassroots. NIF was looking at implementing a rain water harvesting system in its campus to meet part of its water requirements.

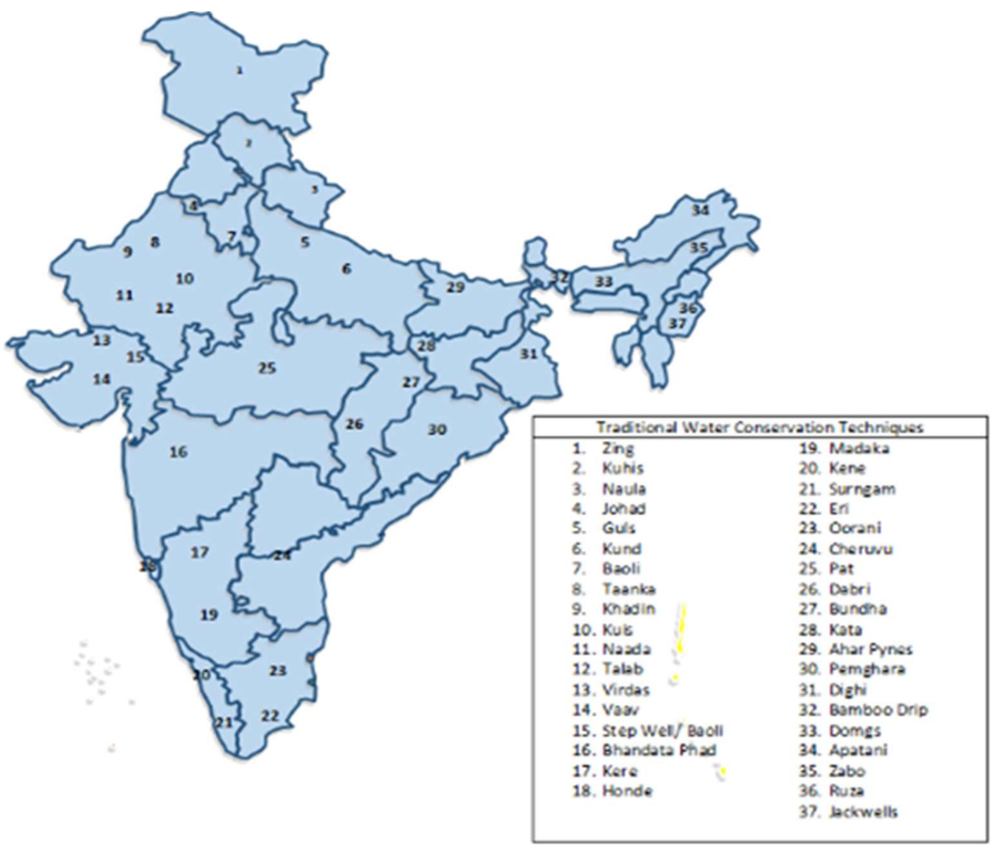


Figure 1: Traditional water conservation systems in India

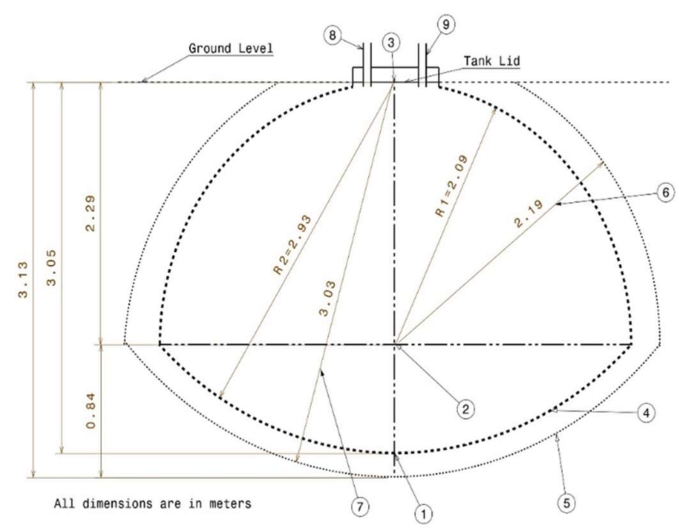
After studying all available traditional techniques, the design, maintenance and cost aspects of rainwater harvesting, it was decided that the construction of an underground tank with brick masonry would be the most cost effective and practical design as compared to other existing designs (Harvesting, 2001). During this period, NIF came across Lok Mitra Trust and its founder Chaitanyabhai Bhatt who were the first in the country to design and build water tanks with saucer shape bottoms and hemisphere top domes, locally known as "matka tank" using bricks. The concept was originally based on the Deenbandhu Biogas plant and modified for use as an underground water storage system. Chaitanyabhai had not only standardized the technique but also trained more than 30 artisans in the construction of the design independently. More than 550 water tanks have been built by him and his team all over India. He has taken a pioneering approach with both methodological and practical viewpoints, providing hands on training and creating a team of practitioners to replicate the design for further advancement of technology.

Material and Methods

Study area

The campus of National Innovation Foundation (NIF) - India is situated in Gandhinagar, Gujarat (23.2156 ^{0}N, 72.6369 ^{0}E). Located in hot and semi-arid climate, the region is basically a flat region with sandy loam soil. The summers are hot to very hot (35 ^{0}C to 45^0 C) and winters are pleasant (15 ^{0}C to 30 ^{0}C). The average annual rainfall is about 803.4 mm mostly during the monsoon season, with the rest of the year remaining dry. Much of the precipitation percolates deep in the ground, due to the nature of soil, resulting in a very low ground water table in the region (Verma, 2014).

NIF has implemented the project of developing four underground rainwater harvesting tank of capacity 24,990 liters each. The depth of tank is 3.13 m, radius (R1) is taken as 2.09 m for making saucer shaped bottom surface and a radius (R2) is taken as 2.93 m for making hemispherical shape top dome (figure 2) with the following objectives: a) documenting knowledge, traditional elements, and skills, as well as preserving the practices of traditional masonry art of making underground water storage tanks out of bricks, b) developing a training manual and creating a unique resource material in the form of a guidebook and study material for development professionals and artisans who follow sustainable practices, c) disseminating traditional knowledge and ancient masonry techniques of a group of practitioners who have this information and want to improve their skill set, d) raising awareness and developing new prospects about this traditional heritage on a local and worldwide level.



Total Capacity (4 tanks) – One Lakh Liters

1. Center of the saucer shaped bottom surface
2. Center for constructing hemispherical dome
3. Center for constructing saucer shaped bottom surface
4. Concrete surface
5. Line of excavation
6. Outer radius of hemispherical dome
7. Radius of excavation for saucer shaped bottom surface
8. Water inlet
9. Water outlet

Figure 2: Blueprint of the rainwater harvesting tank

Determination of Catchment Area:
The catchment area of the NIF building-2, which is L shaped (figure 3), is calculated as:

Catchment Area = (length X breadth) + (length X breadth)
= (37.40 m X 9.80 m) + (19.50 m X 13.30 m)
= 366.52 m^2 + 259.35 m^2
= 625.87 m

Determination of volume of water that can be harvested in a year:
(i) Rainwater endowment: The total amount of water that is received in the form of rainfall over an area is called the rainwater endowment of that area (Kumar, 2015).

Rain water endowment = Catchment area (m^2) X Mean annual rainfall (m)
= 625.87 X 0.8034
= 502.823958 m^3 or 502823.958 L

(ii) Runoff coefficient: Runoff coefficient is a dimensionless factor that is used to convert the total rainfall amounts to runoff amount. In this case as the catchment area is a well-constructed roof, the run off coefficient is taken as 0.9 (Goel, 2011).

(ii) Water Harvesting Potential: The amount of water that can be effectively harvested is called rainwater potentiality (Kumar, 2015).

Rainwater Harvesting Potential= Mean annual rainfall (m) x X Area of roof top (m^2) X Runoff coefficient
= 0.8034 X 625.87 X 0.9
= 452.5415622 m^3 or 452541.5622 L

Determination of Total Volume of tank
(i) Volume of Hemisphere at Top (Hemispherical dome)

Volume (V1) = (2/3) X π X R1^3
= (2/3) X (22/7) X (2.09 X 2.09 X 2.09)
= 19.11 m^3

where, R1 = Radius for Hemispherical dome = 2.09 m
(ii) Volume of Spherical Cap at bottom (Saucer shaped bottom surface)
Volume formula (V2) = (1/3) X π X h^2 (3R2 - h)
= (1/3) X (3.14) X (0.84 X 0.84) X (3 X 2.93 - 0.84)
= 0.3333 X 3.14 X 0.7056 X (8.79-0.84)
= 0.3333 X 3.14 X 0.7056 X 7.95
= 5.88 m^3
where, R2 = Radius for Saucer shaped bottom surface =2.93 m &, h = Height for Saucer shaped bottom surface = 0.84 m

(iii) Total Volume of tank = V1 + V2
=19.11+5.88
= 24.99 m^3 or =24990 L ≈ 25000 L

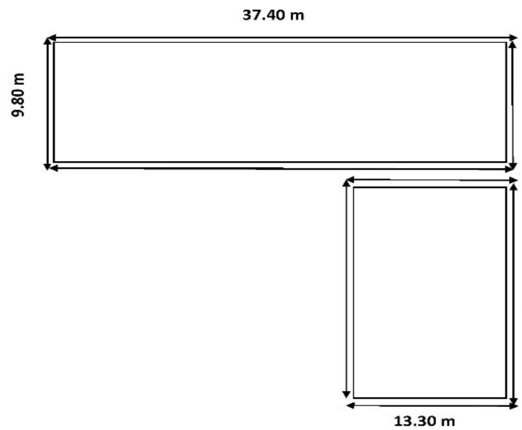


Figure 3: Rooftop/ Terrace area of NIF building-2

Construction Procedure
A blueprint was prepared initially, based on the tank's capacity and location. This was followed by an excavation exercise, which was carried out aligned with the measurements of the tank's size. A vertical rod/pipe was placed in the excavation pit to mark an arch, taking ground level as reference point and 2.93 m as the radius for constructing saucer shaped bottom surface. Similarly, the vertical pipe/rod was marked at 0.84 m from the bottom to build the hemispheric top of the tank, with a radius of 2.09 (figure 2). The soil was then dressed in the shape of a saucer at the bottom. To lay the Plain Cement Concrete (PCC), the dressed surface was slightly moistened and compacted. The bottom inverted dome "saucer" was then built at a thickness of 150 mm. Plumbing pipes were installed concurrently while constructing the water tank to minimize the need for subsequent correction on later stages. Then the PCC was poured on top of the soil and completed according to the blueprint. The hemispherical dome was half brick thick (110 mm) and built from the bottom of the lower inverted dome (however, if the groundwater table is

high and the surrounding soil is loose/black cotton, the dome is built one brick thick). The exterior was plastered concurrently with every 0.75 to 1 m of brickwork to counter balance the weight of the bricks. The dome was completed by the manhole in the center. To prevent water leakage, the inner surface was scraped with a steel bowl to fill the spaces between the bricks, followed by a second layer of plaster and a smooth finish. Finally, on the manhole, the inlet and outlet pipe connections were made, and the entire construction was plastered with cement mortar (figure 4 & 5).

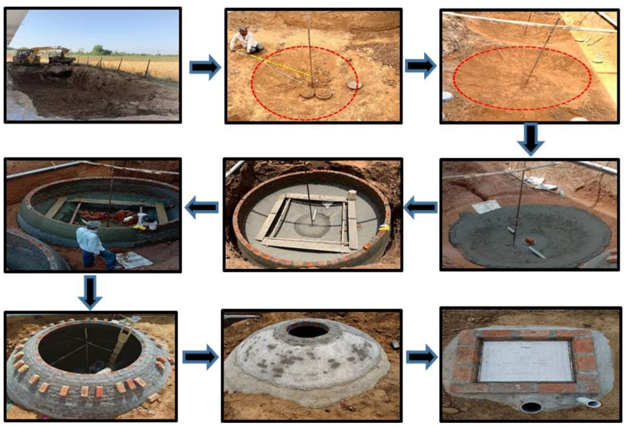


Figure 4: Stepwise construction of Rainwater Harvesting Tank at NIF building.

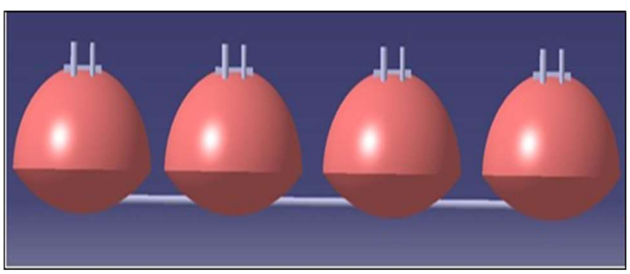


Figure 5: Isometric front view of the rainwater harvesting tank.

Precautions

After construction, there are a few things to be kept in mind, viz. i) avoid planting large trees nearby as their roots might damage underground construction, ii) driving a heavy vehicle over a tank or other heavy object may cause damage to the structure, iii) cleaning and checking the tank for any seepage or cracks on a regular basis has to be undertaken iv) marking the area around the tank for safety has to be undertaken. The absence of appropriate skills to design and construct such subterranean tanks is a key limitation in this approach when compared to conventional ground storage systems. It needs specialized training due to its more difficult construction.

Results and Discussion

Underground dome shaped tanks are considered to be much more cost effective than other types of tanks (Harvesting, 2001). Such underground tanks are larger in size than surface tanks and are appropriate in places where space above ground is limited (Mati, 2012). This brick tank which has a hemisphere shaped top dome and saucer shaped bottom, constructed at NIF, is uniquely conceptualized and takes advantage of geometry when compared to square and rectangle RCC tanks, as it provides better strength and durability to the tank along with its cost effectiveness (5 Rs. / litre). The whole design is derived empirically, the thickness of saucer shaped bottom dome and hemisphere shaped top dome is constructed based on the experience of the artisan. Before laying bottom concrete, the artisan dresses the soil as per the exact profile of the saucer. This is very crucial for effectively transferring the load to prevent the possible damage which may be caused either by load of water or by the negative pressure created from the ground. The least surface area to volume ratio is the main advantage of this dome/sphere shape water tank when compared to the cuboidal tank. So, whenever there is negative pressure due to a higher water table, the same will dissipate due to dome shape, decreasing the chances of leakage and hence adding more life to the tank (Lema et al., 2009). Furthermore, when compared to other expensive water harvesting containers built of masonry, plastic, or RCC, it is a low-cost alternative approach. It is less expensive to build than surface tanks since it does not require reinforcement during construction (Mati, 2012). As subterranean tanks are supported by the earth, the spherical / arch shape design probably provides the necessary strength to hold the water and is safer in earthquakes.

Conclusion

The conservation of heritage, cultural, social or technological, has multiple facets and necessitates a multidisciplinary approach. In these days of scarcity of potable drinking water, one cannot overlook traditional water conservation techniques of our ancestors. To preserve such traditions, it is imperative to protect and promote artisans' skills through adoption of their work. The work of Chaitanyabhai has set an example for professionals, researchers, students, academics, and others to promote sustainable and inclusive development. The next stage for preserving historical legacy and human cultural values is collaboration between stake holders involving multidisciplinary and multi-level approaches. The NIF's effort to build traditional underground water harvesting tanks, is a small step and is expected to go a long way in promoting this innovative masonry technique by keeping this practicing skills of mason alive. This will also evoke the institutional accountability and leadership to adopt such an approach of sustainable development to mitigate the water scarcity and also in the context of climate change. This opensource design can also be replicated by following the guidelines in the manual and the video that is being prepared by NIF. The design can be replicated anywhere by making minor local adaptations depending on the soil type of the region.

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Conflict of interest
The authors declare that they have no conflict of interest.

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