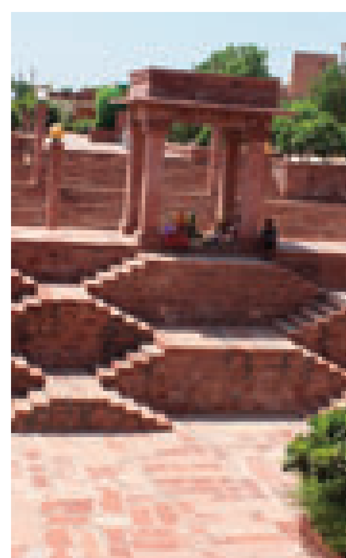



Urban Rainwater Harvesting

Case studies from different agro-climatic regions

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We would like to thank all the implementers, developers, beneficiaries – individuals and organisations who shared their knowledge, ideas and case studies with CSE water researchers, gave their time to patiently answer all queries and provided data, illustration and photographs.

We have collected over 80 case studies from across country, but not all of them are included in the report due to paucity of space. The remaining select case studies from across India will be put up on our website.

Executive Summary

With rapid urbanisation the modern water management relies heavily on the cost intensive long distance transfer of water to meet the widening water demand-supply gap including overexploitation of in-situ groundwater resources. The limited water availability and increasing demand has prompted the need for rainwater harvesting (RWH) as – 'any resource saved is resource created'.

Jawahar Lal Nehru National Urban Renewal Mission (JnNURM) included mandatory amendments in building bye-laws making RWH mandatory in all mission cities. The mid-term review highlighted for the sustainability of reform, urban local bodies (ULBs) require a clear understanding not only in terms of the extent and potential of water augmentation through RWH but also the socio-economic and environmental impacts. Need is to have more information on issues, challenges and potential of RWH across different regions.

India gets an average rainfall of 4000 billion cubic metres per annum that is highly unevenly distributed with respect to time and space, across different agro-climatic regions. The potential of RWH in the area may vary from site to site.

This report has reviewed 12 case studies out of total over 80 RWH projects identified from across India. After detailed analysis of successfully implemented RWH projects from different agro-climatic settings two case studies have been selected – one each from low (scanty) and very high rainfall area.

First, is the case study of a residential complex in Umaid Heritage – *Birkha Bawari* located in Jodhpur, Rajasthan known for low and scanty rainfall. Second, case study is of Goa University campus located in very high rainfall region. In other words, people have implemented RWH, with the excesses of water, and its scarcity. The residential complex in scanty rainfall area collects 2.1 million litres rainwater annually and uses it for meeting the landscaping water requirements and maintaining greenery. While Goa University contributes around 38 million litres to ground water aquifers to maintain sustainable water supply in the campus that is dependent for over 50 per cent its water requirements sourced from groundwater which was declining before the RWH system was implemented.

It is evident that both the systems worked on the principle of RWH in a region for addressing the current water crises but implemented different RWH structures keeping in mind the agro-climatic settings, local hydro-geological settings and depending on water use requirements. Both case studies illustrate different ways in which RWH within water management actions are planned, implemented and judged in respective settings. The case studies scientifically establish the necessity and possibility of RWH in the area that may vary from site to site.

But the potential of RWH is simple; as low as 10 cm of rainwater harvested on 1 ha. area will collect 1 million litres of water – for recharge or storage. The case studies seek to encourage discussion within ULBs or water management organisations on potential of mainstreaming RWH about what they are doing at present and raising questions about what they want to do in the future.

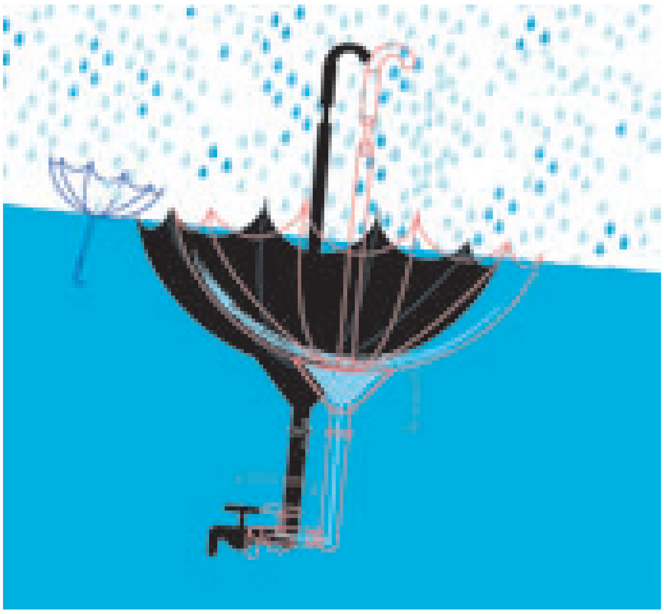
Each town / city should value each raindrop and need to understand that unless we are prudent, indeed frugal, with our use of this precious resource, there will never be enough water for all in town and cities. It is time that municipal and other government bodies make determined efforts to mainstream RWH.

The sustainable water management requires understanding the value of rain, and to make optimum use of rainwater at the place where it falls.

Introduction

India has witnessed a rapid increase in the urban population during last few decades. All towns and cities currently are facing today the problem of increasing water demand supply gap invariably exerting pressure on the water resources and its supply requirements. But the modern water management relies heavily on the cost intensive long distance transfer of water to meet the widening demand-supply including overexploitation of in-situ groundwater resources.

The sustainable water management requires understanding the value of rain, and to make optimum use of rainwater at the place where it falls. In this scenario, RWH can contribute considerably to tackle water crisis. The best option is to harvest the rainwater where we get it and store it appropriately (on surface or into the aquifer) for eventual recovery and use at times of need.



Mainstreaming Rainwater Harvesting for Sustainable Urban Water Management

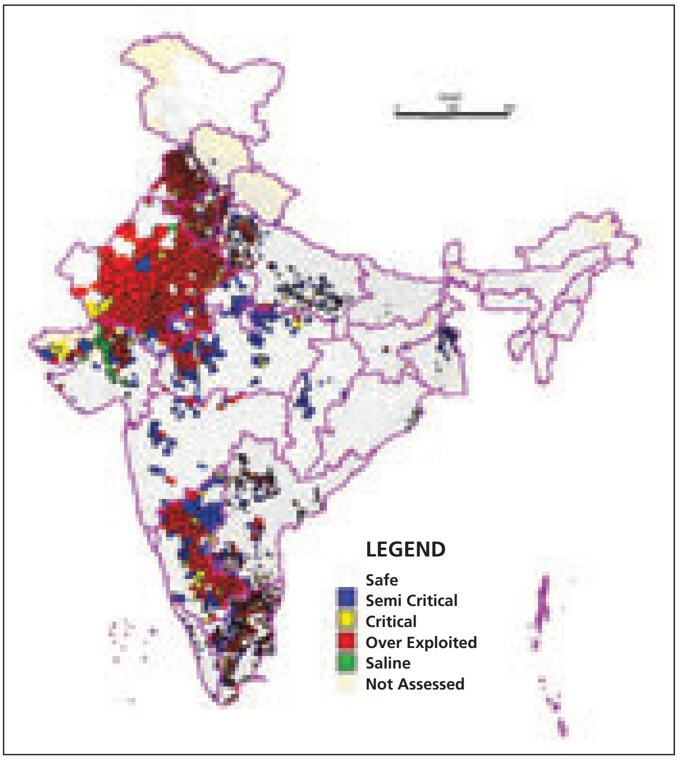
Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water for us. Rivers, lakes and groundwater are all secondary sources of water. In present times we depend entirely on such secondary sources of water. In the process, it is forgotten that rain is the ultimate source that feeds all these secondary sources and remain ignorant of its value.

RWH can be done through two methods; surface storage and groundwater storage. Catchment areas for collection of rainwater include rooftops, compounds, roads, park bare grounds or any other natural or artificial surface. The concepts are simple; conserving the water where it falls, increasing the contact time and area of contact with soil so as to increase the amount of water that enters the aquifers as the groundwater reservoirs forms the most economical means of storage as well as the most dispersed form of supply. For any RWH system the most important components, which need to be examined, are:

- Area contributing to run off (existing / projected) i.e. how much area and type of land use pattern – industrial, residential or general built up pattern of the area and water related infrastructure.
- Hydro-meteorological and physical characters – rainfall duration, general pattern and intensity of rainfall, topography and soil.
- Hydrogeology of the area including nature and extent of aquifer, depth to water levels and chemical quality of groundwater.

With rapid urbanisation and greater areas coming under roofs and concrete structures the water utilities have focused on augmentation from distant sources of water and failing to capture the rainfall that otherwise goes as waste or causes flooding/water logging. On the other hand, the unsustainable extraction and exploitation of groundwater for meeting growing water requirements has placed the aquifers at great peril, lowering the groundwater table in many areas and causing saline water intrusion in various parts of the country. In a span of nine years (from 1995 to 2004), the rate of groundwater withdrawal has reached an "unsafe" level (the districts with the status of groundwater development greater than 70 per cent) in 31 per cent of districts, which is about 33 per cent of land area and 35 per cent of the population.[1,2] The above map shows the over extraction and exploitation of groundwater across India in different regions (see *Map 1: Categorisation of ground water assessment units in India as on year 2012*).

MAP 1 Categorisation of ground water assessment units in India as on year 2012



Source: *Ground water year book (2012-2013), Ministry of Water Resources (MoWR), GOI*

The main source of groundwater resources is recharge through rainfall which contributes to around 68 per cent of total replenishable resources. The annual replenishable groundwater resources of the country as a whole do not show any appreciable change from previous assessments. But the water availability in India is marked with great temporal and spatial variability of annual precipitation in India (see *Map 2: Annual rainfall in India*).

Overexploitation of groundwater due to unregulated extraction beyond the ground water recharge limit is common phenomenon across the regions. With rapid urbanisation and

MAP 2 Annual rainfall in India

Source: *India-Annual average rainfall, Survey of India, www.surveyofindia.gov.in/downloads*

issues/challenges associated with rainfall and groundwater availability in the country, several challenges do exist in the overall urban water supply scenario in India. The cities of the future boast of an unparalleled infrastructure of modern water management as a solution. On the other hand the projected increase in proportion of hard surface will further increase run off while decreasing percolation in the area. However, the realisation is now sinking that rainfall (runoff and flood discharges) constitute a major step toward resource efficiency and conservation that will lead to sustainable urban water management in cities showcasing commitment to adopting good practices in water management.

In 2005, Government of India launched the JnNURM, a flagship programme encouraging reforms to fast track planned

TABLE 1 Summary of JnNURM cities across different rainfall regions

0-40 cm	40-75 cm	75-150 cm	150 cm-above
Low	**Moderate**	**High**	**Very high**
Bikaner, Jodhpur, Dwarka	Agra, Delhi, Faridabad, Chandigarh, Ludhiana, Amritsar, Srinagar, Jaipur, Ajmer, Rajkot, Hyderabad, Pune, Mysore, Coimbatore, Mathura	Raipur, Lucknow, Kanpur, Allahabad, Meerut, Jabalpur, Nagpur, Vishakhapatnam, Nainital, Jammu, Surat, Puri, Ahmedabad, Vadodara, Ujjain, Indore, Bhopal, Indore, Nanded, Madurai, Dhanbad, Asansol, Patna, Bodh Gaya, Jamshedpur, Varanasi, Nasik, Chennai, Bangalore, Ranchi	Mumbai, Panaji, Pondicherry, Trivandrum, Kochi, Bhubaneswar, Calcutta, Simla, Dehradun, Haridwar, Gangtok, Itanagar, Shillong, Kohima, Imphal, Aizwal, Agartala, Guwahati

Source: *Grant Thornton 2011, 'Appraisal of Jawaharlal Nehru National Urban Renewal Mission (JnNURM)'. (Vol. 1)*

development aimed at sustainable urban infrastructure development in identified cities and help them become the effective engines of growth. The Mission, included revision of bylaws to make RWH mandatory in all the buildings and adoption of water conservation measures as an optional reform. Each city was required to take the following actions:[2]

- Incorporate RWH in its mandate which would enable the authority to make budgetary allocations for RWH, set up RWH cell — only for municipal corporation (MC), take up projects to initiate RWH (like MC can promote RWH in public areas).
- MC/Development Authority, as applicable, shall have the powers to amend the existing building byelaws to make RWH mandatory in new buildings.
- ULBs would be under obligation to put the modified building byelaws in public domain invite and incorporate comments on the same before finalizing the modified building byelaws.

The table shows the list of cities across different rainfall regions – low to very high and harvesting potential that may vary region to region *(see Table 1: Summary of JnNURM cities across different rainfall regions)*.

Most of JnNURM mission cities have revised their building byelaws to make RWH mandatory. The following table *(see Table 2: Status of implementation of RWH provisions)* shows the status of RWH provisions and reform before and after the launch of JnNURM.

In the next phase of JnNURM, RWH is recommended to be made mandatory with a non-negotiable status and the responsibility for its implementation would lie with the ULBs.[4] Need is for a clear understanding not only in terms of the extent and potential of water augmentation through RWH but also socio-economic and environmental impacts in different regions.

The concepts of RWH are simple; conserving the water where it falls, increasing the contact time and area of contact with soil so as to increase the amount of water that enters the aquifers as the groundwater reservoirs forms the most economical means of storage as well as the most dispersed form of supply. The final report on appraisal of JnNURM clearly stated that although the majority of the ULBs have made amendments to the building byelaws but very little is known by way of the extent of water conservation achieved since the initiatives have been recently taken and the mechanisms to monitor the same are not yet in place.[4] Although there is no implementation constraints, the mere existence of legislative measures are not adequate and it needs to be the part of mandatory reforms.[4] In other words, for the sustainability of reforms the ULBs need to understand the necessity and possibility of RWH in respective region.

TABLE 2 Status of implementation of RWH provisions

Pre-JnNURM	Post-JnNURM			
	Completed	**In progress**	**Significantly in progress**	**Not done**
Implemented in seven states:	Implemented in fourteen states:	In four states:	In five states:	In one state:
Haryana, Himachal Pradesh, Kerala, Tamil Nadu, Bihar, Uttar Pradesh, Assam	Chandigarh, Uttarakhand, Chhattisgarh, West Bengal, Maharashtra, Madhya Pradesh, Andhra Pradesh, Puducherry, Punjab, Karnataka, Orissa, Gujarat, Delhi, Mizoram	Manipur, Meghalaya, Jharkhand, Jammu and Kashmir	Nagaland, Rajasthan, Tripura, Arunachal Pradesh, Assam	Sikkim

Source: *Grant Thornton 2011, 'Appraisal of Jawaharlal Nehru National Urban Renewal Mission (JnNURM)'. (Vol. 1)*

Methodology

Research frame

The objective of the study is to document case studies and best practices on urban RWH in India from two different agro-climatic regions. The study has documented two case studies one each from scanty rainfall and one from high rainfall region for detailed understanding of challenges and potential of RWH.

The report is underpinned by an interpretive understanding of knowledge, focussing on meaning that is situated in particular context and acknowledges the subjective nature of real world problems related to sustainable water management in rapidly urbanising town/cities in India. The research documents how RWH provisions are understood by relevant actors, and how these different understandings and values are interfacing with policy and practice to produce narratives with the help of two different case studies that are region specific. The aim is to clarify and deliberate about the problems and risks in respective settings and outline how RWH can be done differently. The case studies discussed offer concrete context dependent knowledge and an attempt to capture complexities and contradictions that happen 'on the ground' that may vary from region to region.

The case studies illustrate not just what happened but also why and how it happened and why specific type of intervention (RWH for recharge or storage) and for why not alternative intervention and for what reasons. The case studies illustrate good practice examples and a step towards sustainable urban water management in respective settings and do not illustrate typical examples that can be generalised. The 'case studies' were selected from a long list of potential cases.

Case study approach

Case study approach as a research methodology has been used in the given research. A case study can be defined as an 'in-depth' descriptive, exploratory or explanatory analysis of a person, group or event. It is a story about something unique, special or interesting. A case study gives the story behind the result by capturing what happened to bring attention to a particular challenge or difficulty or success in a project. A case may be selected because it is highly effective, not effective, representative, typical or of special interest.[5,6]

A multi-layered criteria for selection was identified. The list has been tested against a set of criteria defined by the research team and the case studies were purposefully selected.

Data collection and analysis

First, desk review identified over 80 RWH case studies from different agro climatic region in India. Second, 12 case studies (four from low rainfall area and eight from high rainfall area) were shortlisted on the basis of a combination of criteria such as type of RWH structure (storage or recharge), socio-economic impacts, environmental impacts and water supply scenario. Third, two case studies with maximum and high impact have been finalised for documentation against set of criteria.

The collection of data on RWH systems across India was done through a variety of approaches. The initial data collection involved desk and archival research followed by telephonic interviews, site visits, in-person interviews and secondary data collection for shortlisted sites. The goal of the given study is to generate depth of understanding. This entails going after the specific context or a particular piece of information. Therefore, the participants (interviewees) and documents were purposefully selected to help understand the issue/event and meet the overall aim of research.[7,8]

The archival and desk research was followed by site visits to shortlisted sites and in-person interviews with concerned stakeholders. These two activities enabled detailed gathering of in-depth information on RWH structures at the site which included details on design specifications, operation and maintenance, performance monitoring and socio-economic evaluation. The data collected was both quantitative and qualitative.

The selection of interviewees was done using two types of sampling techniques – judgment/purposive sampling and snowball sampling.[9] The initial identification of the potential interviewees was done based on archival and desk research carried out. This was followed by snowball sampling, where during interview process, all the interviewees were asked who they thought should be approached to get information regarding the RWH case study, and those persons in turn recommended others. This snowball effect further helped to identify potential interviewees through referrals.[9] Even specific referrals were asked for who could shed light and was knowledgeable about certain aspects of the case and would provide specific information related to the study such as socio-economic impacts, technical information, etc.

The analysis of data collected and information from interviews have been used to explain, what was the status of the case study in general sense and supported by interviews. The analysis was validated by comparing it to information obtained from interviews and through extensive discussions within the research team. The addition, the analysis and results were validated through follow up discussions with interviewees and other individuals or organisations representing interest in mainstreaming RWH for sustainable urban water management. The case studies identified and shortlisted is presented (see *Table 3: Summary of case studies reviewed).*

The selected two case studies have been discussed in the following section.

TABLE 3 Summary of case studies reviewed

Area	Selection of case studies		
	Initial	**Draft**	**Final**
Low/scanty rainfall	• Umaid Heritage, Jodhpur • Central Arid Zone Research Institute (CAZRI), Jodhpur • NIIT University, Neemarana • Pearl Academy of Fashion, Jaipur	• Umaid Heritage, Jodhpur • Central Arid Zone Research Institute (CAZRI), Jodhpur • NIIT University, Neemarana	**Umaid Heritage, Residential Complex, Jodhpur**
High rainfall	• Residence of NK Kanodia, Alipur, Kolkata, West Bengal • Jamnabai Narsee School, Mumbai, Maharashtra • Deputy Chief Minister's Residence, Barik Point, Shillong, Meghalaya • Gariahat Mall, Kolkata, West Bengal • Bishop Cotton School, Shimla, Himachal Pradesh • Government Hospital, Angamaly, Kochi, Kerala • Goa University, Taleigao, Goa • Prabodhan Krida Bhawan, Mumbai, Maharastra	• Goa University, Taleigao, Goa • Prabodhan Krida Bhawan, Mumbai, Maharastra	**Goa University, Taleigao, Goa**

Case study: Rainwater harvesting in low / scanty rainfall area

Umaid Heritage Housing Complex, Jodhpur (Rajasthan)

Objective
The *Birkha Bawari* is designed as a monumental RWH structure, in Umaid Heritage Township which is based on the concept of both '*Kunds*' and '*baoli*' (also referred as '*Bawari*') which were the traditional practice of RWH in Rajasthan and Gujarat.[10] The *Bawari* structure acts as a recreational space for inhabitants as well as storage of rainwater – and good example of sustainable urban development practice in a low rainfall region, demonstrating the value of water by conserving rainwater.


CSE TEAM

***Entrance foyer similar to* 'Kund'**

Location
The Umaid Heritage site is a private township located in southeast of the Umaid Bhawan Palace (*see Map 3: Location map of Umaid Heritage in Jodhpur, Rajasthan*). The site is located in the city of Jodhpur where the traditional water management system is getting gradually destroyed due to modernisation and urbanisation. The city is second largest city of Rajasthan with major physiographic units of sand dunes, alluvial plains, ridges and hillocks.

Climate profile
The climate of Jodhpur is generally hot and semi-arid. The rainy season is spread from late June to September month. The climate is of an extreme type, with the variations in temperature range being very high. The average annual rainfall is approximately 32 cm with 10-12 days of rainy days per year. In summer, the maximum temperature is around 42° C and the minimum temperature is around 37° C. In winters, the maximum temperature is around 27.5° C and the minimum temperature is around 15.5° C. Jodhpur is bright and sunny throughout the year. The rainfall pattern shows that, Jodhpur has scanty and uneven rainfall; also the evaporation and evapo-transpiration losses exceed the normal average precipitation.[11]

Water scenario
Jodhpur city located close to the Thar desert, historically had devised a system of getting water through its lakes and step-wells. In 1897-98, the system was replaced by public piped water supply distribution in the city. Jodhpur stores the raw water it gets from the Rajiv Gandhi Canal in two impounding reservoirs, the Kailana and Takhatsagar.[12] The water level in the city was 24 m below ground level (mbgl) in 1985 but the water table is 2.4 mbgl since 1998 after the waters of the Rajiv Gandhi Lift Canal started reaching Jodhpur. The residents stopped using traditional water resources after the canal began supplying water, causing rise in water table. But the city suffers from water logging on roads and open spaces in rain season due to high water table.

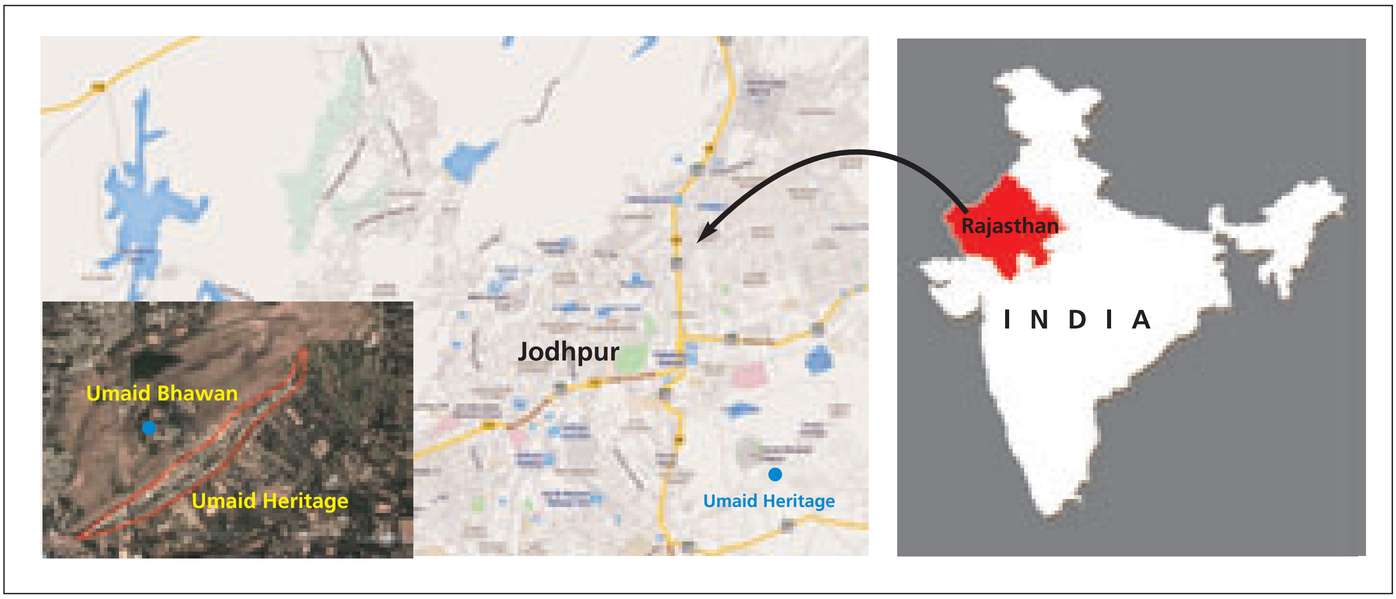
According to the National Institute of Hydrology, Kailana Lake's elevation and leakage losses could be contributing to the increase in groundwater level. The city has recorded high ground water level with brackish quality of the water.[13] Thus it


A MRIDUL

***Series of storage tanks similar to* 'Bawari'**

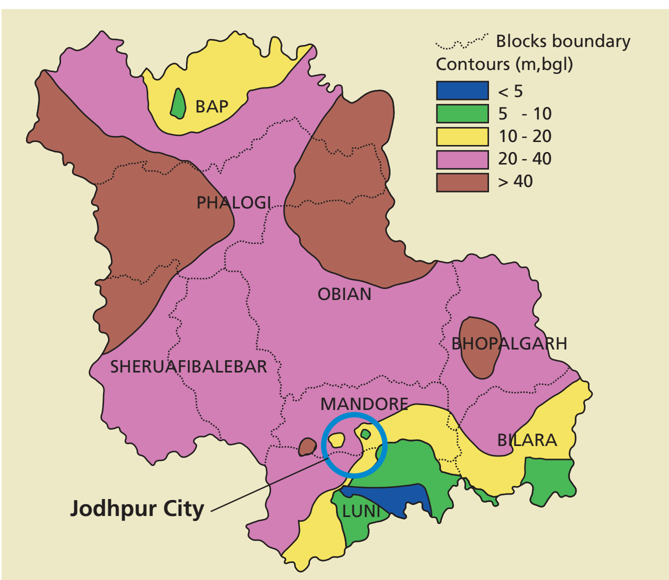
> **"The ground water level of the city is high and the quality of the water is brackish. Thus it is recommended to harvest and store the rainwater than recharge as alternate source of water supply."**
>
> *– O P Poonia, Central Ground Water Board, Jodhpur*

MAP 3 Location map of Umaid Heritage in Jodhpur, Rajasthan



Source: *Google Map Image*, 2014

MAP 4 Depth of groundwater in Jodhpur District



Source: *Report on Ground water scenario, Jodhpur district Rajasthan, Central Ground Water Board, Ministry of Water Resources (MoWR), July 2008*

is recommended to harvest and store the rainwater than recharge as alternate source of water supply.[14]

While the walled city of Jodhpur has high water table due to external factors, the water table at Umaid heritage residential complex site is still quite low in the range of 20-40 mbgl (*see Map 4: Depth of groundwater in Jodhpur District*). In the absence of adequate water supply the cost of water tanker for supplying 10,000 litres water is around Rs. 800-1000/.

Rainwater harvesting system

In the foothills of Umaid Palace, the residential complex is planned and developed as an integrated township named Umaid Heritage. The Umaid Heritage is spread over 110 acre of area with 410 plotted houses. The layout of the township is designed with number of green cores/ garden dividing and making different sectors. A RWH system to collect rainwater falling on entire site has been developed. The rainwater is collected in an open storage designed similar to *Bawari* and integrated with housing complex as recreational area. The RWH system collects around 30 per cent of the potential of rainwater on the site to maintain green area by meeting its horticulture water requirements. The project overview is summarised above *(see Table 4: Salient features of the RWH system at Umaid Heritage Residential Complex).*

The lowest part of the site has been planned and designed as RWH storage structure to collect run off by gravity flow *(see Diagram 1: Birkha Bawari and the catchment area).*

The RWH storage structure is inspired from traditional RWH structures in the region and named as *Birkha Bawari.* While the traditional *baolis* and *kunds* were used to extract ground water, the *Birkha Bawari* is being used to catch rainwater from the site catchment area.[10] Apart from storage and conservation of rainwater, the project also highlights the sustainable storm water management in the housing complex, as it collects all the

TABLE 4 Salient features of the RWH system at Umaid Heritage Residential Complex

Parameters	Details of the RWH system
Total catchment area	110 acres
Green area irrigated	15 acres
Capacity of RWH structure (*Bawari* – the storage tank)	17.5 million litres
Volume of rainwater harvested	Approx 21.1 million litres per annum
Cost of system (in Rs)	80 million
Savings per annum	2.36 million per annum
Year of RWH system implemented	2010

Source: *CSE Team,* 2014

DIAGRAM 1 *Birkha Bawari* and the catchment area

Source: *A Mridul*

runoff from the site minimizing water-logging in residential complex.[15]

Technical specifications and design of the RWH system

The technical specifications of catchment area, design of conveyance system including sedimentation and rainwater storage tank, details of operation and maintenance of the system and benefits have been discussed in following sections.

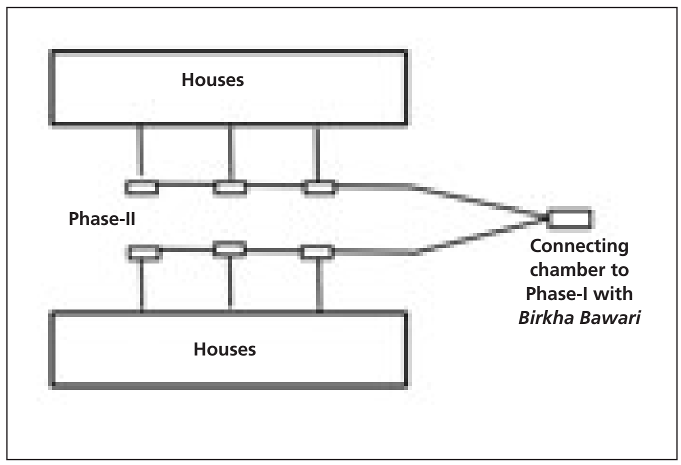
Catchment area

The entire area of the site acts as catchment area for the system to catch water *(see Diagram 1: Birkha Bawari and the catchment area)*. The rainwater is collected from the open areas through the natural slopes as well as from the roof top of houses which in turn are connected with natural slope of the site through drainage conduits. The nature of the catchment area is rocky with high runoff coefficient. The entry of rainwater is blocked from the inlet wall for first two flushes of rainfall to avoid debris and dust particles going to *Bawari*.[10,16]

Conveyance system

The complex is designed in two phases, one with apartments called phase-II and other with plotted housing called phase-I. The rainwater is collected from rooftop and road channels through storm water drains; open channels and slots *(see Diagram 2: Conveyance system of runoff reaching Birkha Bawari)*. The runoff from the phase-II is collected from the storm drains and connected to the drains in phase-I sloping towards the RWH structure – *Birkha Bawari,* located in Phase I of the complex.

DIAGRAM 2 Conveyance system of runoff reaching *Birkha Bawari*



Source: *CSE Team*

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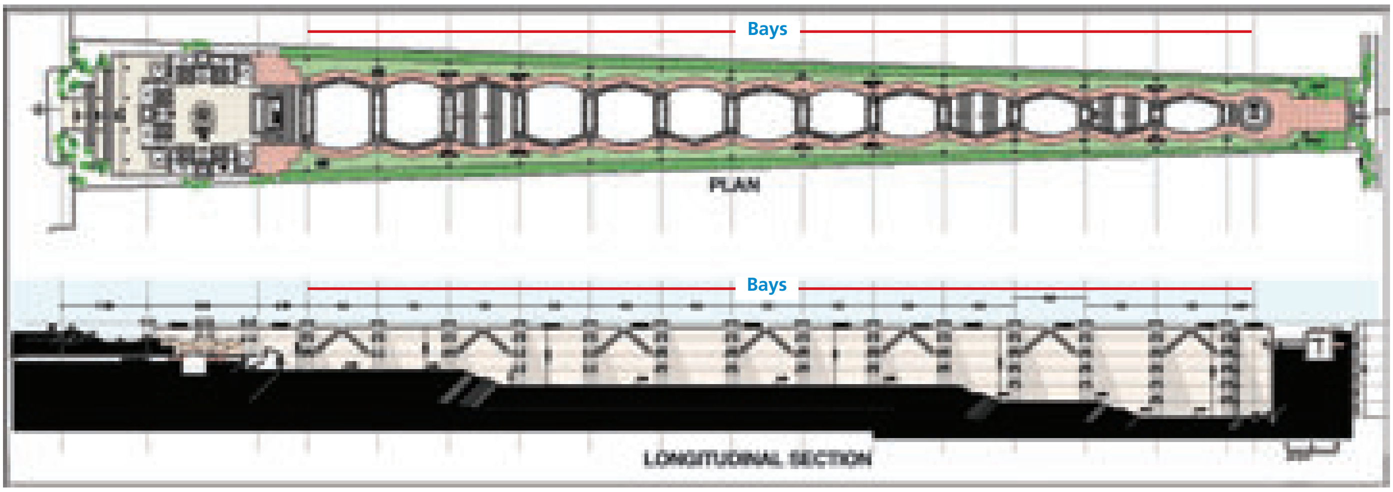
Inlet for road side drainage

CSE TEAM

Open channels and grated underground storm water drains

DIAGRAM 3 **Plan and section of the *Birkha Bawari***



Source: *A Mridul*

Birkha Bawari: Sedimentation and storage tanks

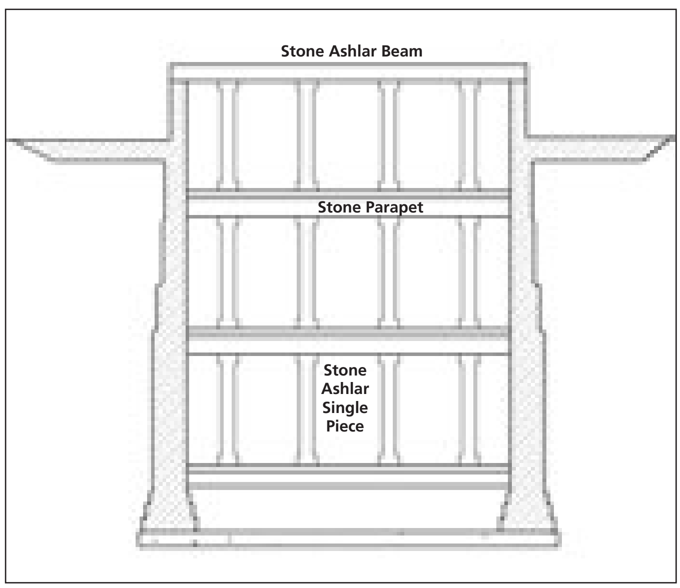
The *Birkha Bawari* consists of longitudinal open rainwater storage structure. The system consists of series of constructed tanks making it a linear 135 metre long structure. The water enters from both the sides of underground longitudinal storage structure (*Bawari*), which holds 17.5 million litres of harvested rainwater annually and serves as a reliable source of water for meeting landscaping water requirements in an otherwise water scarce region.[17]

Rainwater comes from either side of the structure (*Bawari*) and first enters into the hidden settlement tank – see the longitudinal section through the *Bawari* in the following figure *(see Diagram 3: Plan and section of the Birkha Bawari)* from there, water flows to the series of tank with deepest depth of 18 metre below the ground level. The structure is designed with 7 metres of free board, i.e. the volume of water will require only 11 metres of depth, while the depth of the tank is 18 metre.[18]

Traditionally, a *Bawari* can hold water for a long time because of almost negligible water evaporation when compared to other water bodies, thus the steep depth of the tank provide shade to water and help in reducing evapo-transmission losses. The maximum depth of the structure was constructed to be 18 metre below the ground level. The sectional plan and elevation for one storage tank has been provided in following figure *(see Diagram 4: Sectional plan and elevation for one of the storage tank)*. The structure is spread over 5750 square metre. The vertical free board also provides shade to the stored water from sun, thereby minimizing evaporation and algae formation. The table (*see Table 5: Design specifications of Birkha Bawari*) provides the design specifications for *Birkha Bawari*. The system is planned for storage of 100 per cent anticipated runoff from the catchment area with provision of bypass system in unforeseen conditions.

To reduce the cost of the structure, the thickness of retaining walls is reduced by efficient structure design and local labor as well as on site available building material was used. The structure is made out of number of vaulted walls placed opposite to one another and held against each other by an arched support structure. The vaults on opposite sides nullify each other's thrust and counter balance each other thereby, reducing the thickness to 0.7 metre.[19] Moreover, the structure is constructed from locally available building material, majority of sandstone quarried from the site.

DIAGRAM 4 **Sectional plan and elevation for one of the storage tank**



Source: *CSE Team*

TABLE 5 **Design specifications of *Birkha Bawari***

Parameters	Specification
Length	224 m
Width	10.5 m
Average Depth	11 mbgl
Maximum Depth	18 mbgl
Average Water Depth	7 m
Wall Thickness	0.7 m

Source: *A Mridul, 2013*


A MRIDUL

Vaulted walls for tank construction

Socio-economic and environmental benefits

The residential complex has around 15 acres of green area. The landscape is rich mix of trees, plants and gardens as an integrated part of the complex. The stored water from the *Birkha Bawari* is used for maintaining green area of the housing complex. The rainwater stored can meet around 8-9 months of landscaping and horticultural water requirements.[15,21] The RWH project is a high visibility and high impact intervention with considerable social and economic benefits to direct users as well as its surrounding environment in terms of improvement in micro climate.

Operation and maintenance

Birkha Bawari is an example of large scale structure at group housing level which requires periodical maintenance. Presently the responsibility of operation and maintenance is taken by developer for the entire infrastructure of the complex including *Birkha Bawari – open rainwater storage system*, which will be handed over to the resident's society in due course.

The first flush system is provided to avoid first two spells of rainfall by providing valve system which needs to be operated manually. The *Birkha Bawari* needs to be cleaned twice a year, pre and post monsoon. Around 10-15 daily wage workers are employed for each time for one to two days to clean the whole structure. It costs around 12000 rupees per annum to maintain the system. For the underground structures of sedimentation tanks, provision for entrance to manually clean the structure was incorporated in the project design. Due to proper operation and maintenance, hygiene conditions are maintained. No problem of mosquitoes or foul smell has been observed and the *Bawari* is regularly used as recreation space by inhabitants of the housing complex.[20] In future the developer proposes to introduce fish in the water for improving quality of water. It is also proposed to create awareness among the residents for upkeep of the catchment and storage tank to avoid contamination of water stored in the structure.

"For developing such large housing, it is not sustainable to depend only on municipal supply and ground water supply, structure like *Birkha Bawari* is the need for creating one's own source of water"
— Anu Mridul, Principal Architect

"The *Bawari* structure helps to clear the water on roads within minutes, thus no water logging is found in this housing unlike other parts of the city"
— Ashan Khan, Architect & Supervisor

"The beautiful monumental *Bawari* is one of the feature of the housing giving the royal ambience and serving the environment which inturn adds to the property value of the plots and flats"
— Ajay Mathur, Marketing Manager and Resident

"The *Bawari* is presently used to water landscaped area, later on when the water cost will increase, it will be like a life line. The *Bawari* adds to aesthetic value, water safety and garden maintenance"
— C V Arora, Chartered Accountant and Resident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Entrance for manual O&M of first sedimentation Tank – stair step cover


CSE TEAM

Entrance for manual O&M of second sedimentation tank


A MATHUR

Green landscape area of Umaid heritage

Economic benefits

The RWH system captures around 21.1 million litres of rainwater reducing the dependence on municipal water supply and groundwater extraction. During past three years almost 50 per cent less groundwater is now extracted from bore wells on the site.[21]

The average cost of water tanker (10,000 litres) in Jodhpur is Rs. 800 – 1,000/-, thus by using the rainwater as alternate source of water about Rs. 2.36 million are saved annually.[22]

The housing has a great property value as it demonstrates perfect combination of good architectural design and well maintained green spaces in a scanty rainfall area.[22] The implemented RWH system in housing complex not only provided alternate source of water supply but has also reduced the overall dependence on municipal storm water infrastructure. The complex has never been experienced water logging in the last two years when compared to rest of the city. The structure has also added to the aesthetic value to the housing plots which in turn raised the value of the whole housing society. Moreover the project also provides green landscaped area to the site, which will be sustainable over the years without much depending on the municipal or ground water supplies.[21,22]

Social and environmental benefits

Umaid heritage in Jodhpur is considered a prime housing complex catering to elite and high income group. The *Birkha Bawari* has considerably added to the identity of the project and improvement of micro climate. The implemented RWH is clear valuable resource cum facility for the residents and demonstrates to other practitioners the value of rainwater and its potential re(use).

The RWH structure not only provides the environmental benefits but also increased the aesthetics of the site.[20,21] There are extensive landscaped area and gardens in the residential area that are used by residents for recreational activities and social gathering, thereby leading to area appreciation and building a social community around the structure.[23]

In addition to the above the RWH structure helps in awareness creation on the overall concept of RWH. The project site is frequently visited by universities/ schools students and researchers.[22] The structure in the housing society is an absolute example of how the environmental benefits can be achieved with simple integration of historic concept to better utilise and conserve the in-situ resources.[23]

"The housing colony promises green areas and cleanliness with traditional water harvesting monumental structure which clears off the water from the roads and makes us the proud resident of the society"

— Kamla Jain, Resident

"Life is seen in relation to air, water, land, plants. *Bawari* structure shows such example of cultivated nature which in turn creates culture"

— Dr. Bharadwaj, Resident

Case study: Rainwater harvesting in very high rainfall area

Goa University Campus, Taleigao (Goa)

Objective
The key objective of the RWH project in Goa University is to arrest declining groundwater levels and recharge the aquifers to reduce dependence on the overstretched municipal water supply for a more sustainable water supply on the campus.

Location
Goa city is located along the western coast of India (*see Map 5: Location map of Goa University in Taleigao, Goa*) and the university campus is located on the outskirts of Panaji (the capital city) spread over nearly 173 hectares on the Taleigao plateau overlooking the Zuari river joining the Arabian Sea. The campus is located on a plateau in the island of Tiswadi and has unique geological features. The area has hard laterite rock of variable thickness on the top (*see Diagram 5: Geological cross-section of the study area*) followed by a thick sequence of clays, and fractured and weathered basement rocks forming deep seated confined aquifers.[24]

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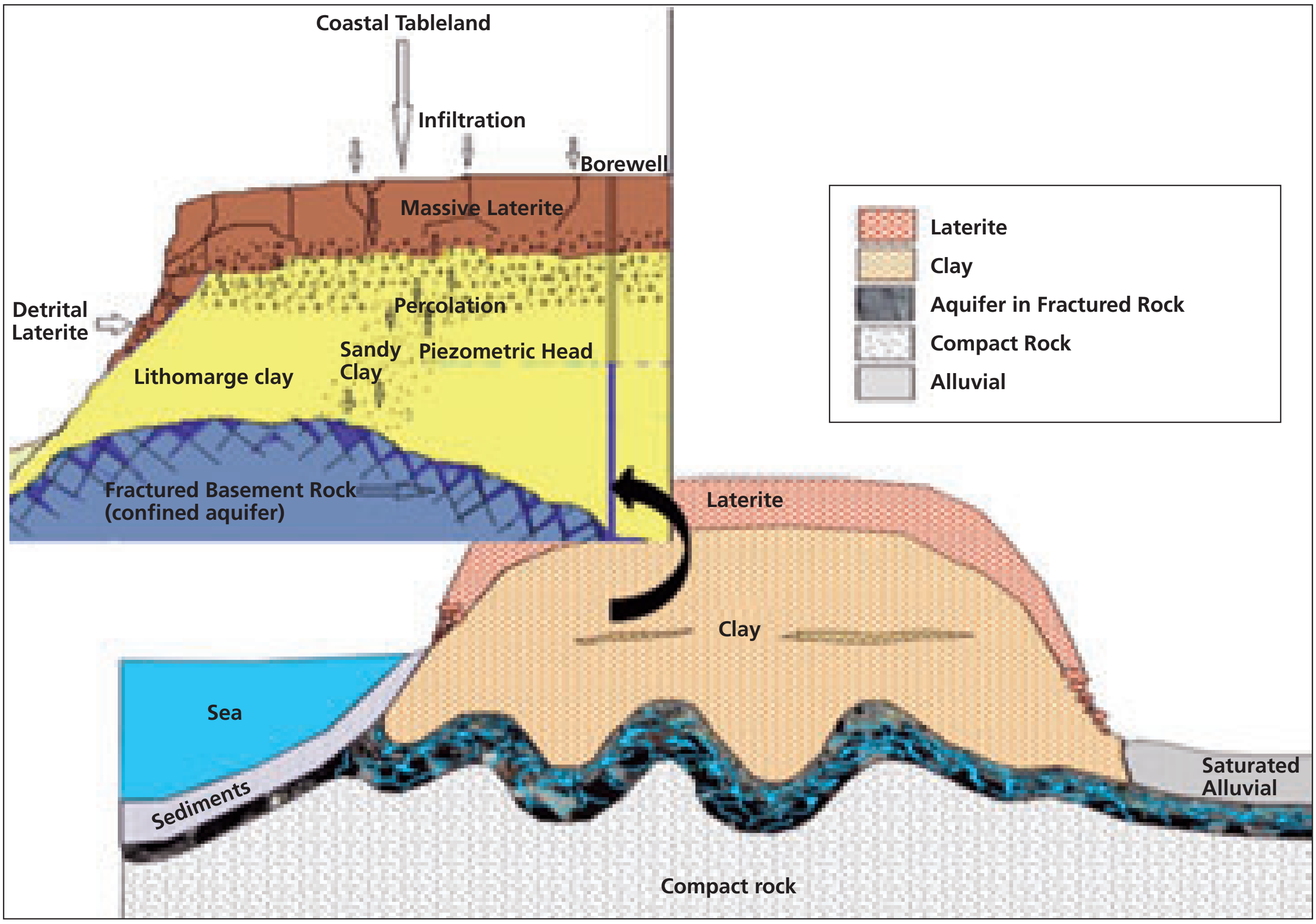
Hard laterite on the surface in Goa University

Climate profile
Goa is known for its tropical climate. The area has mild and pleasant weather entire year due to its location along the coast. There is very less fluctuation in weather with maximum temperature rise to 35°C in April and May months. The

MAP 5 **Location map of Goa University in Taleigao, Goa**

Source: *Google Map Image*, 2014

DIAGRAM 5 **Geological cross-section of the study area**



Source: *AG Chachadi, 2013*

monsoon period begins in the month of June and remains till September. Rainfall is heaviest at the mountain ranges and on its western slopes, which gradually reduces towards the coastal plains. The rainfall is very heavy and the strong winds are experienced during the rainy season in Goa.[25] The region receives very high rainfall around 250 cm per annum in the coastal belt and 400 cm per annum in the vegetated regions. The average rainfall of Goa is approximately 320 cm per annum.[26]

Water scenario

There are not enough water supply facilities to meet increasing water usage due to growth of population, increase in number of tourists, and rise in living standards, resulting in serious imbalance in supply and demand of water in Goa. The current water supply is dependent on both groundwater and surface water. The groundwater contributes to over 33 per cent of the water supply in Goa and is considered as safe.

The depth to water level depends on the nature of aquifer. In shallow unconfined aquifer the water levels are less than 10 mbgl but in confined deeper aquifers the water levels are in range of 15-85 mbgl depending on the undulating nature of the basement rock and seasonal fluctuation.[24] Due to steep hydraulic gradient and highly permeable phreatic aquifers, the dynamic ground water resource in and around campus gets depleted quickly rendering scarcity even for drinking water during summer months.

The university has around 1500 staff and student population. The existing water demand of university is around 0.45 million litres per day.[24] Around 50 per cent of the water supply depends on public water supply and remaining from the existing twelve bore wells on the campus. During summer the public water supply is further reduced by almost 50 per cent. This results overexploitation of groundwater and has resulted in drying up of few bore wells on the campus.

> **"Goa receives high rainfall but because of its geological characteristics, most of the water is drained into the sea. Since, Goa has large plateaus and they act as a sponge to store water, it is beneficial that we have RWH"**
>
> *— Sujeet Dongre, Programme Coordinator*
> *Centre for Environment Education, Goa*

Rainwater harvesting system

In 2007 the Goa University initiated the plan to develop RWH system for recharging the fast depleting aquifers. Keeping in mind the vast potential of harvesting rainwater on the campus a RWH system has been implemented at the university under supervision of Prof. AG Chachadi, Department of Earth Sciences, Goa University.

The existing rainwater system has two main structures – one main structure for harvesting surface runoff constructed in year 2007 with a catchment of 1.5 hectare mainly unpaved area and second, rooftop harvesting system constructed in year 2008 for harvesting the runoff mainly from built up area on campus *(see Table 6: Salient features of the RWH system at Goa University).*

The project is good example of private sector engagement. According to Prof. Chachadi RWH system of university was funded partly from his research fund and remaining generous contributions from – Sociedade de Fomento Industrial Pvt Ltd; Bhagavathi Ana Labs Ltd; Timblo Pvt Ltd; V M Salgaocar & Bro Pvt Ltd, Vasco (Goa) and Mineral Engineering Services and Coca Cola Ltd.

Technical specifications and design of the RWH system

Goa University area is located on confined aquifer with layers of impermeable material above and below them. The depth to aquifer in the Goa University campus varies from 65m to 110m below ground. The topography of the basement rock is fractured and weathered water bearing zone is undulating in nature.[24,27] The RWH at university was designed keeping the site characteristics. The detailed technical specification of the implemented RWH is discussed in the following section.

Site 1: Surface runoff harvesting

Catchment area and conveyance system

The total catchment area contributing to runoff for the surface runoff RWH structure is 1.5 hectare to the natural depression – a pond (*see Photograph: Surface runoff catchment area of the RWH structure*).

In the beginning before creating RWH structure, the site was de-silted and leveled. To maintain clean and contaminant

TABLE 6 Salient features of the RWH system at Goa University

Parameters	Details of the RWH system
Total catchment area	173 hectares
RWH structure (2 no.s)	Recharge trench in natural depression/pond Recharge bore well for rooftop water harvesting
Total volume of recharge (in year 2010)	39 million litres (38 million litres surface water from and 0.9 million from roof top run off)
Cost of system (in Rs)	0.16 million
Savings per annum (in Rs)	4.4 million per annum
Year of implementation of the RWH system	2007, 2008

Source: *AG Chachadi, 2013*

runoff recharging the aquifers a protective rubble wall was built around this natural depression pond as the pond receives mainly runoff from the unpaved surrounding catchment. A deep trench (dimension 20m x 10m and 2m) is built at the centre of the pond and a retention concrete wall of 0.5m height was built around this trench to prevent direct entry of the pond water. The runoff water passes into the deep trench ensuring the suspended particles settle down before water enters into the sand filter (dimension 3m x 3m x 3m). Finally after getting through the sand filter the water enters the main recharge well trench (dimension 3m x 3m x 4m size).

The deep bore well is perforated both at the surface as well as at the bottom where it is exposed to the aquifer. The runoff water enters through these perforations wrapped with nylon cloth and directly enters into the aquifers at deeper levels.[24,28]

The bore well is drilled to a depth of 89m below ground and has tapped an aquifer at 65m depth. In the well water enters through the top 5m length of the slotted casing pipe. Inside the bore, water is released to the aquifer between 65m and 89m depth through a slotted casing pipe. Between 89m and 65m depth range the bore well is cased with blank pipe as the geological layer in this depth range is made up of clay (*see Diagram 6: Cross sectional view of surface runoff – RWH system).*

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RWH structures – deep trench, sand filter and recharge well

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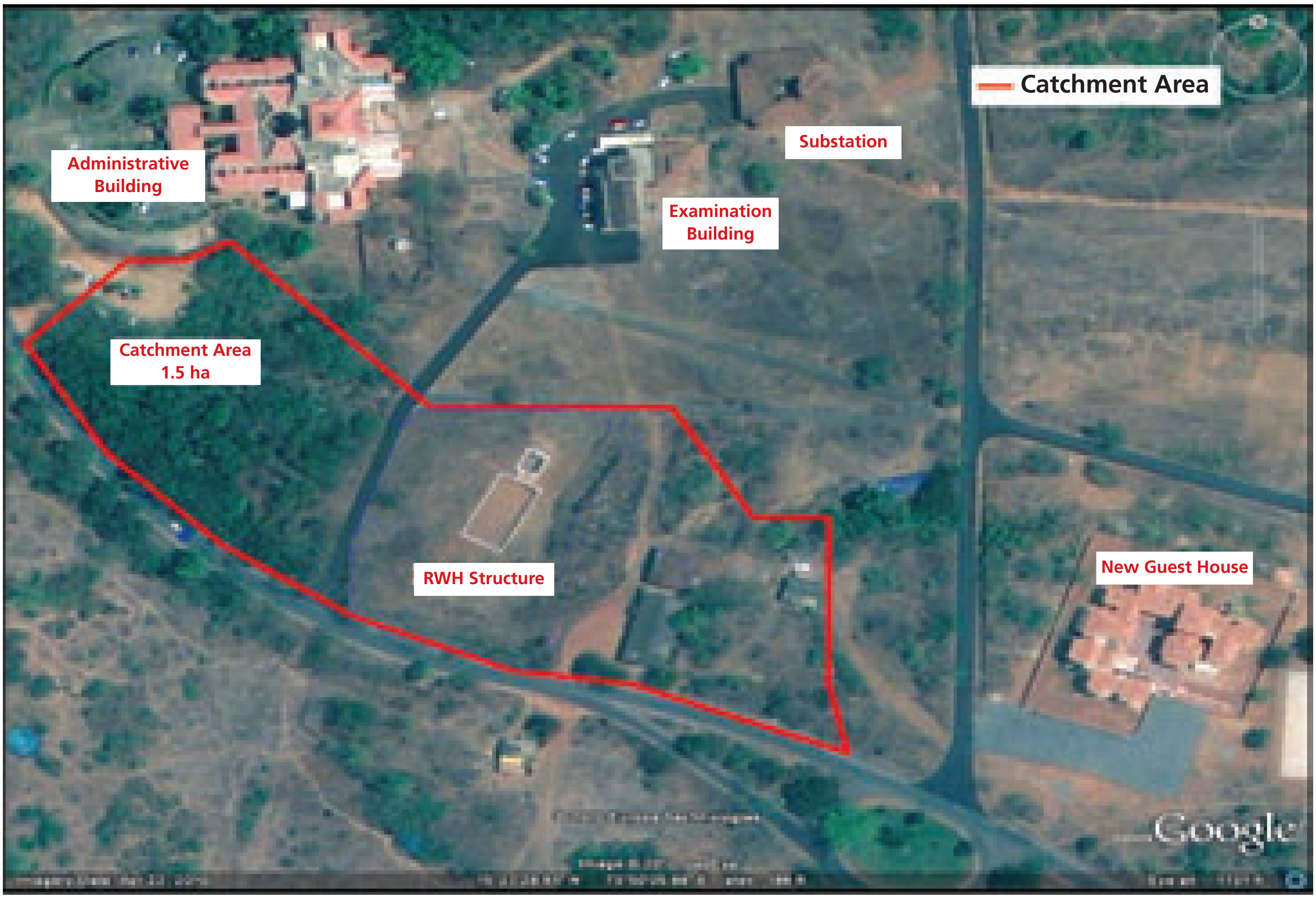
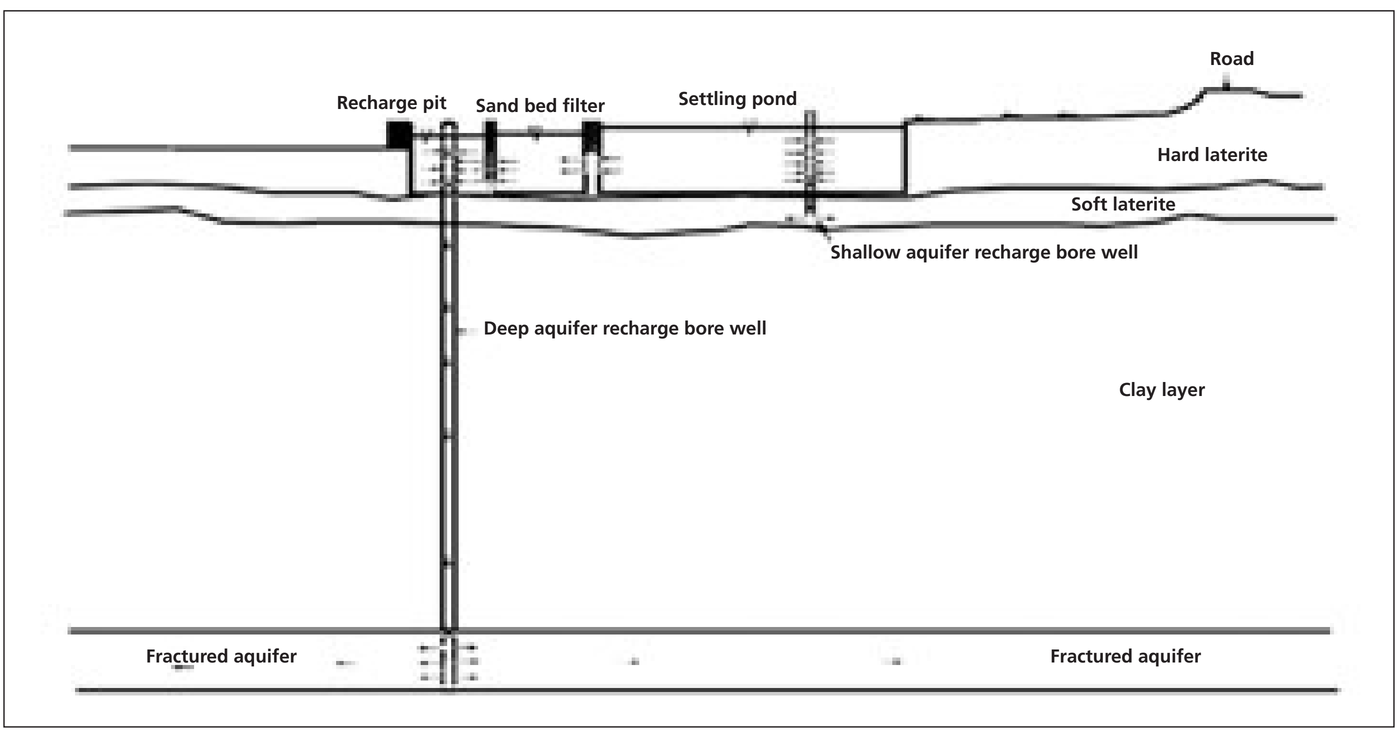
Deep recharge bore well



Surface runoff catchment area of the RWH structure

DIAGRAM 6 Cross sectional view of surface runoff – RWH system



Source: *AG Chachadi*, 2013

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Plan showing the roof water harvesting catchment and structure

Site 2: Roof water harvesting

Catchment area and conveyance system

The roof areas of about 400 m^2 form presently the catchment for the RWH structure at this site. At present the conveyance for the runoff from the rooftop from boy's hostel and the electronic building is complete and feeds to the existing recharge. The rooftop of the girl's hostel, men's hostel and remaining department buildings will be connected in next phase and work is under progress *(see Photograph: Plan showing the roof water harvesting catchment and structure).*

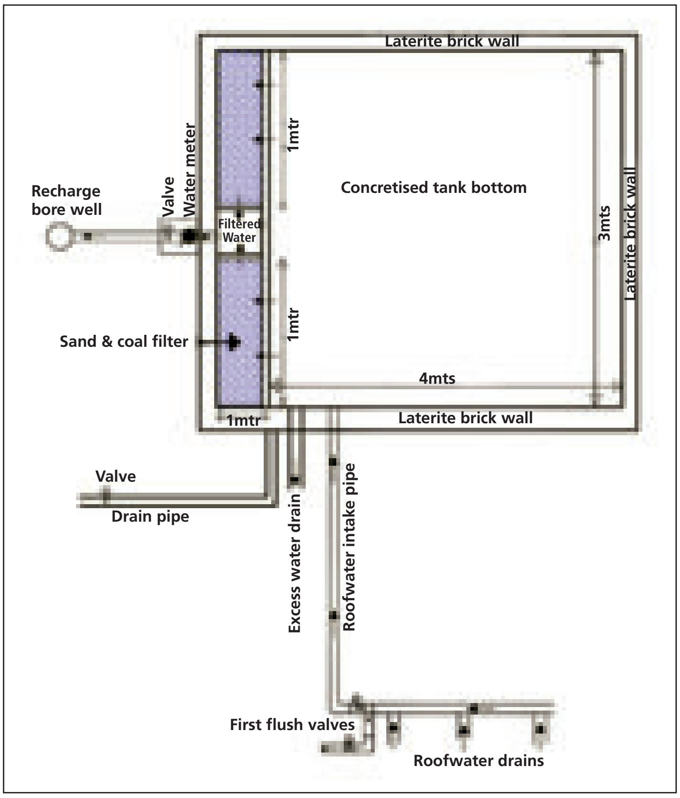
The diagram gives the detailed structural design of the roof top RWH structure at the university (*see Diagram 7: Structural design and layout of the rooftop water harvesting system*).

The rooftop water intake pipes bring water to the storage tank made of concrete base and laterite brick wall. The rooftop runoff storage tank has capacity of 100,000 litres. The rooftop runoff passes through a sand and coal filter. After filtration the water is taken to the nearby recharge bore well feeding aquifer at 100 mbgl depth. To avoid any pollutants from rooftop entering the aquifer first 15 minute rainfall is flushed away using the manually operated flush valve. The photographs on next page shows the PVC pipes used to collect rooftop rainwater and the first flush valve.[27,28]

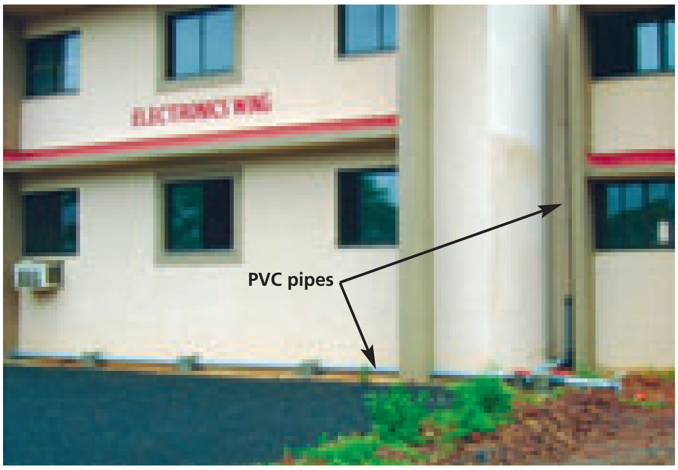
Operation and maintenance

Every year the system and catchment areas are cleaned twice before and after monsoon. The first flush system has been

DIAGRAM 7 Structural design and layout of the rooftop water harvesting system



Source: *AG Chachadi*, 2013



Roof water conveyance system – PVC pipes

First flush device in use in the roof top RWH site on campus

provided to avoid first one or two spells of season rainfall and has to be operated manually. The manual de-silting of settlement tank is also undertaken twice pre and post monsoon for better efficiency of the RWH system. Due to regular O&M no mosquito breeding case has been reported. The annual maintenance for both the systems costs Rs. 8,000 to 10,000 per year.[24] In addition the water quality is tested at periodic interval to ensure good quality runoff is recharging the aquifer.

Socio–economic and environmental benefits

The university caters to water supply for 1500 both resident and non-resident staff as well as students. The estimated demand for water supply is 0.45 million litres per day to meet water requirements of the administrative blocks, teaching blocks, hostels, residential quarters and landscaping. The total groundwater recharge during 2010 from both the structures was 39 million litres. In 2010, Site 1 estimated recharge was 38 million litres (*see Table 7: Recharge per year from surface runoff RWH structure (Site 1)*).

The roof area for the Site 2 is about 400 m^2. The site received a record recharge in the year 2010 due to heavy rainfall of 3.7 m.[24] The performance of the system in terms of water harvested and recharged into the groundwater through bore well during last three year (2008 to 2010) is given in the table (*see Table 8: Performance of rooftop RWH structure (Site 2)*).

The RWH has been contributing considerably in recharge of the local aquifer resulting in improved yield and sustainable extraction of groundwater. The water is now provided on sustainable basis particularly during summer when the public water supply also decreases to less than 50 per cent of the supply. As a result since 2007-08 the water supply has not been interrupted or dependent on any alternate source of water

TABLE 7 Recharge per year from surface runoff RWH structure (Site 1)

Sl. No.	Item	Details
1.	Total drainage area contributing surface runoff	15,000 m^2
2.	Monsoon rainfall year 2010	3.7 m
3.	Surface runoff collected	55.5 million litres
4.	Estimated recharge (70%) to sub surface through recharge bore well	38 million litres

Source: *AG Chachadi, 2013*

TABLE 8 Performance of rooftop RWH structure (Site 2)

Year	Water recharged (litres)
2008	2,60,000
2009	1,80,000
2010	9,00,000

Source: *AG Chachadi, 2013*

supply. In terms of water availability the volume of groundwater recharged during 2010 can meet about 78 days of campus water supply.[24]

Economic benefits

The basic aim of the implemented RWH system at university was not to bring down the water bill but to recharge the aquifers that contribute more than 50 per cent of water supply. With increasing constraints in public water supply the university authorities had to depend on groundwater extraction in summer to meet the public water demand – supply gap. But each unit of water conserved through RWH will have the

"The system has contributed towards convenience/ease in water accessibility and usage to some extent as the groundwater storage has been augmented and decline in water levels is arrested. In the absence of this augmentation the wells would have gone dry by now and we would have to relocate our pumping well systems elsewhere in inconvenient locations"

— Prof. AG Chachadi, Department of Earth Science, Goa University, Goa

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Green area at the Goa University campus

corresponding saving on the water bill. In fact the capital cost incurred for RWH system at Site 1 involving surface water harvesting has been recovered in just 5 years. Site 2 involving rooftop harvesting payback of capital cost is projected to be recovered in next 5-6 years if one works out the unit cost of public supply water at the delivery end in Goa.[29]

The RWH system at university has resulted substantial increase in the aquifer yields is confirmed from the well yield tests carried out on two bore wells located in close proximity of the recharge structure during May 2009. Within one year of operation of the first recharge structure well yields have increased by 13 per cent to 15 per cent showing the recovery in the groundwater levels.[24] The improved yields also mean less electricity usage for pumping groundwater and savings in costs.

A water tanker of 10000 litres capacity costs around Rs. 800-1000/-. In economic terms the RWH system has resulted estimated Rs. 2.8 million per year savings to university that would otherwise be required to arrange water supply from water tankers.

"As neighbor within 3 kms from the site and as expert the RWH in the Goa campus is set up as an example for other institutes and commercial entities to show the benefits of RWH"
— Pradip Sarmokadam, Director, Lila Digital & Environmental Solutions Pvt Ltd, Goa

"The system as devised by Goa University, with or without modifications/alterations as per site conditions would go a long way in decreasing the load on the treated water supply and improve the water development scenario in Goa"
— Sandeep T Nadkarni, Chief Engineer & Ex-Officio Addl Secretary to Govt. of Goa, Water Resources Department, Goa

"The RWH system in Goa University campus has brought about a change in the state. This has been serving as a place of learning on resource conservation especially by the high school students and individuals. Besides this, the Government of Goa after seeing the success of these experiments has made RWH a mandatory for industries, housing colonies and institutions in the state"
— Prof. AG Chachadi, Department of Earth Science, Goa University, Goa

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School student group at RWH site

Environmental benefits

The reduced pressure on the public water supply system and improved recharge has a positive environmental impact. At small scale, the system contributes toward the resource conservation. This activity can also earn carbon credit in terms of energy conservation for in-situ water augmentation on Campus instead of sourcing water from distant sources of water supply.[29] The increase in availability of water has also contributed university maintain its lush green landscape round the year and improvement in the micro climate.

Social impact

The RWH system implemented on the campus has become a platform of creating awareness, information dissemination, and learning about groundwater conservation methods. Various stakeholders NGOs, government officers, school children, and citizens), industry representatives, researchers regularly visit the site.

Prof. Chachadi and team have developed a module of teaching for the villagers and other stake holders and organise workshops at panchayat and school levels to disseminate the experience and create awareness about water and its quality.[24,29]

The International Centre, Goa located adjacent to university has also installed RWH systems after the success at University. The centre harvests 2.5 million litre rainwater.[30] The university RWH has influenced and encouraged several institutes and industries in Goa to implement of RWH structures.

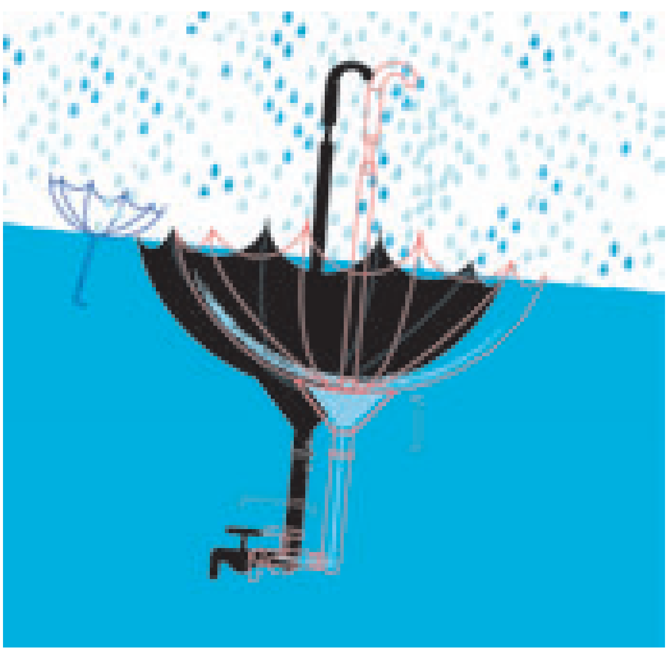
Implications and Conclusion

The modern water management relies heavily on the cost intensive long distance transfer of water to meet the widening demand-supply including overexploitation of in-situ groundwater resources. The sustainable water management requires understanding the value of rain, and to make optimum use of rainwater at the place where it falls. With rapid urbanisation and greater areas coming under roofs and concrete structures the water utilities have focused on augmentation and failed to combine traditional wisdom with modern engineering.

The report discusses both case studies with over arching framework of different rainfall agro-climatic region – low / scanty and very high rainfall and defines type of RWH implemented within context. In both cases it is clearly evident that the selection of system is site and context specific. For planning and delivery of any RWH the information and data to be considered include: geological boundaries; hydraulic boundaries; inflow and outflow of waters; storage capacity; porosity; water resources available for recharge, natural recharge; water balance; depth of aquifer and tectonic boundaries that may vary from site to site.

The framework presented in the report is drawn on geographical focus and variation of rainfall in different regions. But the framework presented in this report with help of case studies may not be applicable in all cases, and there may be other more specific context for particular cases.

The report with the help of case studies seek to encourage discussion within ULBs or water management organisations on potential of mainstreaming RWH about what they are doing at present and raising questions about what they want to do in the future.



It is time that municipal and other government bodies make determined efforts to mainstream RWH. The sustainable water management requires understanding the value of rain, and to make optimum use of rainwater at the place where it falls.

Each town / city should value each raindrop and need to understand that unless we are prudent, indeed frugal, with our use of this precious resource, there will never be enough water for all in town and cities.

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ABBREVIATIONS

bgl	Below Ground Level
cm	Centimetre
CAZRI	Central Arid Zone Research Institute
CGWB	Central Ground Water Board
CSE	Centre for Science and Environment
EPA	Environment Protection Agency
GL	Ground Level
ha	Hectare
JnNURM	Jawaharlal Nehru National Urban Renewal Mission
m	Metre
MC	Municipal Corporation
MoWR	Ministry of Water Resources
NGOs	Non Government Organizations
NURM	National Urban Renewal Mission
PVC	Polyvinyl Chloride
RWH	Rainwater Harvesting
ULBs	Urban Local Bodies

GLOSSARY

Aquifer: Any underground formation of soil or rock which can yield water.

Artificial recharge: Any man made scheme or facility that adds water to an aquifer.

Bawari: A hindi term used for 'stepwell'. It is a well or a pond in which water may be reached by descending a set of steps.

Borewell: Small diameter wells which are generally deeper than the open wells.

Catchment: A geographical area, defined by topography, from which all runoff water will drain into a reservoir. Often used as a synonym for a watershed or a river basin.

Conveyance system: The component of the RWH systems that include the gutters and pipes that carry the water from the catchment to the storage tank or recharge well. The filter screens and first-flush diverters are also included in this component.

First flush system: An installation typically on the downpipe (from the roof or gutter) that diverts the initial 'dirty' wash off the roof when it starts to rain from entering the tank or recharge well.

Groundwater: The water retained in the intergranular pores of soils or fissures of rocks below the water table.

Gutter: A channel installed along the edge of a roof that carries collected rainwater toward the storage.

Kund: A hindi term used for an open tank or small reservoir in which rainwater is collected for drinking purpose.

Permeability: The property of soil or rock, which allows the passage of water through it.

Phreatic Aquifer: Phreatc aquifer is the area in an aquifer below the water table in which relatively all pores and fractures are saturated with water.

Runoff: Runoff is the term applied to the water that flows away from a surface after falling on the surface in the form of rain.

Stone Ashlar: A finely dressed (cut, worked) masonry that has been worked until squared or the masonry built of such stone.

Water table: The level of water within intergranular pores of soil or fissures of rock, below which the pores of host are saturated.

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