MANAGING GROUNDWATER SUSTAINABLY IN RURAL AREAS

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Chapter 1: Introduction

- India uses around 230 cubic kilometre of groundwater annually. This is 25 per cent of world's total annual groundwater consumption.
- India's rural population—comprising more than 60 per cent of India's population—depends on groundwater-based sources.
- Six drinking-water supply programmes have been launched for rural India (until 2019). But the programmes prior to 2019 suffered slippages from full household coverage to no coverage.
- Only 16.70 per cent of rural households had tap-water connections until 2019.
- In 2019, Jal Jeevan Mission (JJM)—which emphasizes safe and sustainable water supply at the household level—was launched.

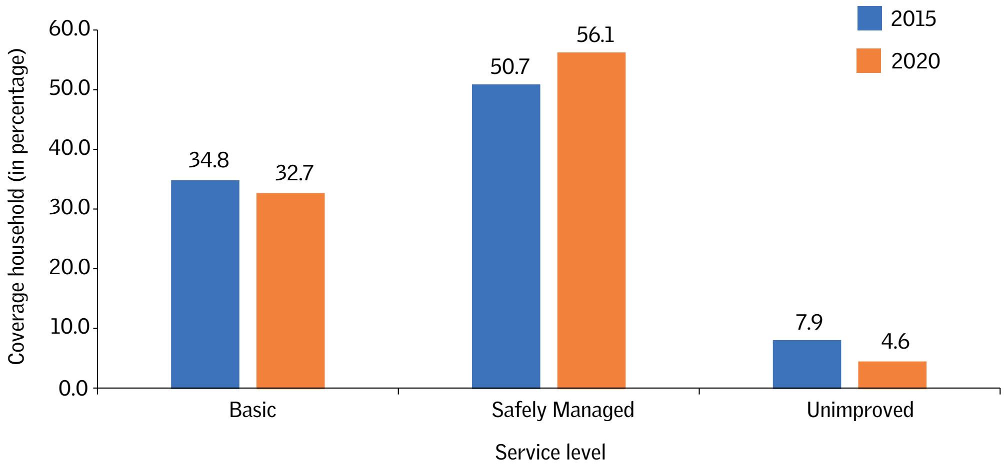
More than 60 per cent of India's population resides in rural areas. India needs to ensure safe and sustainable drinking water for these households. Over 80 per cent of the water is extracted from underground water. A large amount of water is also exploited for irrigation. The quality of groundwater is also challenged due to anthropogenic and geogenic reasons.

The latest report from the Central Groundwater Board shows that the states of Rajasthan, Haryana, Uttar Pradesh, Madhya Pradesh and Karnataka—which comprise more than 25 per cent of the country's land area—show huge stress in groundwater reserves.[1] For example, Delhi, Haryana, Rajasthan and Punjab extract more groundwater than their annual recharge.

Since the First Five-Year Plan, six schemes—apart from several committees and amendments—have been launched by the government. These were mainly groundwater schemes. The schemes, however, did not meet the target of providing access to drinking water to rural households.

The United Nations Millennium Development Goals (MDGs) are eight goals that United Nations Member States agreed to try to achieve by 2015.[2] In 2015, India achieved 93 per cent household coverage of access to improved water supply in rural areas. However, with the shift from the Millennium Development Goals (MDGs) to 17 Sustainable Development Goals (SDGs), the new baseline estimates that only 56 per cent of rural households are using safely managed drinking water.[3] The focus of six of the SDGs is on achieving universal and equitable access to safe and affordable drinking water for all that by 2030.

Graph 1: Drinking-water coverage in rural regions of India (2015–20)



Source: Progress on WASH in healthcare facilities 2000–2021: Special focus on WASH and infection prevention and control (IPC). Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2022.

Comparison of data of the Joint Monitoring Programmes for 2015 and 2020 shows there is been a slight improvement in the supply of safely managed drinking water—from 50.7 per cent coverage (households) to 56.1 per cent—but there is still a long way to go in the provision of safe and equitable water supply in rural India[4] (see *Graph 1: Drinking-water coverage in rural regions of India [2015–20]*).

Issues and challenges

Drinking water in India is largely derived from groundwater—which contributes to 40 per cent of drinking-water supply—that is extracted via handpumps, borewells, tube wells, dug wells and surface water. Government data shows that groundwater is the most reliable source of drinking water for nearly 43 per cent of the rural population in the country.[5] Recent government data shows that plunging groundwater levels and poor quality of groundwater have increased dependence on surface-water sources for drinking water.

National Sample Survey Organisation NSSO data shows that only one in every five households in the country has access to piped-water connections. Rural areas continue to lag in terms of access to piped water as compared to urban areas. Around 58.3 per cent of households still rely on hand pumps, tube wells, public taps, piped water from neighbours, protected or unprotected wells, and private or public taps for their water. As much as 48.6 per cent of rural households have to survive without access to an improved source (uncontaminated/safe) of drinking water throughout the year.

Competing demands from agriculture, businesses and communities are also straining rural resources. Two-thirds of India's 718 districts are affected by extreme water-depletion, and the current lack of planning for water safety and security is a major concern.

One of the challenges is the high rate of groundwater depletion in India. Groundwater from over 30 million access points supplies 85 per cent of drinking water in rural areas.[6] A growing population has led to an increased demand for water, resulting in falling water tables and shrinking or drying up altogether of many water sources. Population growth and massive exploitation of groundwater for irrigation have lowered per capita water availability from 5,000 m^3/year to about 1,800 m^3/year, with water tables dropping to below 1,000 feet in many regions.[7]

Due to the proliferation of drilling over the past few decades, India is the world's largest user of groundwater. It uses an estimated 230 cubic kilometre of groundwater per year, i.e. over a quarter of the global total.[8] Moreover, aquifers are depleting in the most populated and economically productive areas. If current trends continue, in 20 years about 60 per cent of all India's aquifers will be in critical condition.[9] Climate change will further strain groundwater resources, with serious implications for the sustainability of rural drinking-water sources in the long run.

Groundwater resources in the country have also been found to be highly polluted due to the presence of fluoride, arsenic, nitrates, iron and heavy metals as well leaching of harmful pesticide and fertilizer residues. Toxins from untreated industrial wastes and landfills as well as bacterial contaminants from the surface soil and water sources can also contaminate groundwater. Central Groundwater Board (2014) data reveals that as many as 66 million people are drinking water with fluoride levels beyond permissible limits in India, leading to dental and skeletal fluorosis. Contamination of drinking water with arsenic is rife in the states of West Bengal and Bihar as well as in Uttar Pradesh, Madhya Pradesh and Karnataka, leading to arsenic poisoning and cancers.

It is estimated that waterborne diseases have an economic burden of approximately US $600 million a year in India. This is especially true for areas affected by drought and flood, i.e. a third of the country, in the past few years. Excess fluoride in India may be affecting tens of millions of people across 19 states, while, equally worryingly, excess arsenic may affect up to 15 million people in West Bengal, according to the World Health Organization.[10]

There have been several rural water-supply programmes but they failed mainly because of drying up of sources. To make a source sustainable, recharge of the source is necessary. Using rainwater as drinking water has also proved to be viable in the case of contaminated groundwater. Therefore, while a clean and regular supply of water needs to be ensured, sustainability of the sources also needs to be ensured for longevity of schemes.

Schemes and programmes

When Prime Minister Modi announced the Jal Jeevan Mission from the ramparts of the Red Fort on August 15, 2019, India kicked off its seventh major programme since Independence to ensure safe drinking-water supply to rural India. While the plan still remains ambitious—to provide tap-water connections to all rural households by 2024—the question is whether the country learnt enough from the past failed attempts to get it right this time round.

India has a long history of unsuccessful attempts to supply drinking water to its villages (see *Figure 1: Timeline of rural drinking-water supply schemes in India*). The Indian Constitution, adopted in 1950, made water a state subject and gave all citizens the right to safe drinking water. Safe drinking water was one of the priorities of the country's First Five-Year Plan (1951–56), which asked state governments to build the required infrastructure to provide basic water supply to rural areas. State governments, however, focused only the easily accessible villages till the mid-1960s.

In 1969, India launched the National Rural Drinking Water Supply Programme. With technical support from UNICEF, 1.2 million borewells were dug and 17,000 piped-water connections were issued under the programme. In 1972–73, the country rolled out the Accelerated Rural Water Supply Scheme (ARWS) to improve rural access to safe drinking water. A year later, during the Fifth Five-Year Plan, ARWS was replaced with the Minimum Needs Programme, whose objective was improving the overall living standards of people. Owing to its slow progress, the Centre reintroduced ARWS in 1977–78.

In 1986, ARWS was put into mission mode, with the formation of the National Drinking Water Mission. In 1991, it was renamed the Rajiv Gandhi National Drinking Water Mission. Three years later, the 73rd Constitutional Amendment assigned Panchayati Raj Institutions the responsibility of providing drinking water.

Figure 1: Timeline of rural drinking-water supply schemes in India

Early Independence	1949	• The Environment Hygiene Committee (1949) recommended the provision of safe water supply to cover 90 per cent of India's population in a timeframe of 40 years.
	1950	• The Constitution of India conferred ownership of all water resources to the government, specifying it as a state subject and giving citizens the right to potable water.
	1969	• The National Rural Drinking Water Supply programme was launched with technical support from UNICEF. Rs 254.90 crore was spent during this phase; 1.2 million bore wells were dug and 17,000 piped water-supply schemes were provided.
Transition from technology to policy	1972	• The Accelerated Rural Water Supply Programme (ARWSP) was introduced by the Government of India to assist states and Union territories to accelerate the pace of coverage of drinking-water supply.
	1981	• India as a party to the International Drinking Water Supply and Sanitation Decade (1981–90) declaration set up a national-level Apex Committee to define policies to achieve the goal of providing safe water to all villages.
	1986	• The National Drinking Water Mission (NDWM) formed.
	1987	• The first National Water Policy drafted by the Ministry of Water Resources.
Restructuring phase	1991	• NDWM renamed Rajiv Gandhi National Drinking Water Mission (RGNDWM).
	1994	• The 73rd Constitutional Amendment assigns Panchayati Raj Institutions (PRIs) the responsibility of providing drinking water.
	1999	• "Government-oriented supply-driven approach" to the "people-oriented demand-responsive approach"
Consolidation phase	2002	• Nationwide scaling up of sector reform in the form of Swajaldhara.
	2004	• All drinking-water programmes were brought under the umbrella of the RGNDWM.
	2005	• The Government of India launched the Bharat Nirman Programme for overall development of rural areas. The target was to provide drinking water to 55,069 uncovered habitations and those affected by poor water-quality.

Source: Drinking Water Quality in Rural India: Issues and Approaches, WaterAid

In 1996, the now-defunct Planning Commission carried out a sample survey in 87 districts across 16 states to understand the progress made with ARWS. It found the scheme only covered 86 per cent of the sampled villages and even there the water supply remained erratic. The Planning Commission found excess iron, fluoride and bad odour made the water non-potable in many states. This was because the scheme relied predominantly on groundwater, with no plans of water recharge.

The sinking groundwater levels meant that several villages that were initially "covered" under the scheme slipped back to "not covered" status. Also, around 87 per cent of extraction structures for water were not operational, suggesting poor maintenance.

In 1999, the Centre rolled out the Comprehensive Action Plan (CAP 99) to increase the coverage of ARWS to the "not covered" and "partially covered" rural habitations. It also rolled out the Sector Reform Programme (1999–2000) on a pilot basis to achieve self-sufficiency in drinking water in 67 districts across 26 states through community participation. In 2002, the programme was modified and launched as Swajaldhara to be implemented in "villages, Panchayats, blocks where people come forward to own, implement and maintain their water sources as per their choice". Under the scheme, the community had to contribute 10 per cent of the capital cost (5 per cent in case of SC/ST-dominated villages). In 2007, community contribution was made optional. In 2004, all the drinking water programmes were brought under the Rajiv Gandhi National Drinking Water Mission.

Over and above this, the Bharat Nirman Programme, launched in 2005, had a rural drinking-water supply component, which took care of all uncovered habitations identified under CAP 99. The Bharat Nirman Programme also faced limited success in addressing the problem of villages rolling back on progress. According to report released by the Comptroller and Auditor General of India (CAG), in most years between 2002 and 2007 the existing schemes could cover only about 50 per cent of the target habitations.

In 2018, CAG carried a performance report[11] in 27 states on the implementation of the National Rural Drinking Water Programme during 2012–17. According to the report, 0.48 million habitations slipped from "fully covered" to "partially covered" during the period. This was primarily because rural India saw an 80 per cent increase in deep tube-wells between 2006–07 and 2013–14.

In 2017, the Centre launched the Har Ghar Jal programme, with the objective of ensuring safe drinking water to all households with piped supply. By April 1, 2018, however, as per the records of the Department of Drinking Water and Sanitation, only 20 per cent of rural households were connected to piped water. The promise was to cover 35 per cent of rural households in 2018–19, along with enhanced water entitlement for each household. Under Har Ghar Jal, the ministry also increased drinking-water supply in rural areas to 55 litre per capita per day (lpcd).[12] In 2019, Jal Jeevan Mission replaced ARWS.

An analysis of the previous schemes suggests they failed due to four major reasons. First, owing to their dependency on groundwater, they failed to ensure sustainable water sources. Second, they failed to create a sense of ownership among the community towards the drinking-water supply. For this reason, the bulk of the infrastructure that the previous schemes created are now defunct as a result of poor maintenance. Third, progress of the previous projects were seldom shared with the public—sharing the progress would have been a good way of sensitizing the people. Fourth, mismanagement of funds meant that even though India spent Rs 200 crore on rural water supply, the problem persists.

Departure from the past

Jal Jeevan Mission addresses at least partially the key issues that led to the failure of the previous schemes. The scheme, for instance, says that depending on the availability, villages can be connected to either surface-water sources or groundwater. It also says that water sources need to be recharged and protected.[13]

The scheme also has a major focus on sensitization of the communities and implementing officers at all levels. One of the stated key objectives is to "Take up all support activities like Information, Education and Communication (IEC), training, development of utilities, water quality laboratories, water quality testing and surveillance, research development, knowledge centres, capacity building of communities etc. to make the mission successful." Currently, however, the majority of the funds are being used to create infrastructure. As per government data, 22 per cent villages are still to set up Village Water Sanitation Committees, which have the crucial responsibility of maintaining and overseeing water supply on a day-to-day basis. The capacity of the members of the village level also needs to be improved.

The programme has a robust dashboard where centralized progress of the scheme is pushed out for the general public. This much-needed step helps villages understand how other villages are progressing and can play a major role in encouraging villages into action. The dashboard maps every village with water sources, water treatment plants, purification plants, storage, delivery network, community bathing and washing block, and community sanitary complex. It does not, however, locate the source sustainability structures like rainwater harvesting and groundwater recharge.

The scope of the programme also includes preparedness for "natural disasters or unforeseen challenges", implement on a case-to-case basis bulk water transfer to the villages and set up treatment plants and distribution systems, bring in technological interventions to supply safe water wherever water quality is an issue, and undertake grey-water management.

The story so far

India has 193.6 million rural households of which only 32.4 million—or 16.7 per cent rural households—had tap-water connections at the start of Jal Jeevan Mission. As on January 3, 2023, the number of rural households with tap-water connections increased to 108.7 million, or 54.14 per cent, as per the programme's dashboard. This means the Mission needs to cover 76.3 million additional rural households (47.3 per cent) in the next two years. So far only five states and Union territories (UTs)—Haryana, Goa, Andaman and Nicobar Islands, Puducherry, Daman and Diu, and Dadra Nagar Haveli—have achieved the Har Ghar Jal status with tap-water supply to all rural households. Four more states—Telangana, Punjab, Himachal Pradesh and Gujarat—have reported to have achieved the Har Ghar Jal status and their claims are being verified under the scheme.

A lot is riding on Jal Jeevan Mission. Its success will ensure India maintains its open-defecation free status and achieve the Sustainable Development Goals on water and sanitation. The scheme is making quick progress, but a major part of rural India remains to be covered.

Chapter 2: Step-by-step planning for augmentation of groundwater sources

- Different blocks of populated states in India face a rapid decline of groundwater.
- The need of the hour is to arrest the plunging groundwater levels and also improve the quality of groundwater wherever required.
- The solution comes through groundwater recharge.
- The planning and designing of groundwater recharge structures depends on the physiography, soil, geology and groundwater levels.
- As a first step to decide groundwater-recharge systems, estimation of demand and supply of water—i.e. water balance—is essential.

Overview: Groundwater extraction in India

In most low-rainfall areas of the country, availability of utilizable surface water is so low that people must depend largely on groundwater for agriculture and domestic use. The problem has been compounded due to large-scale urbanization and growth of megacities, which has drastically reduced open lands for natural recharge. In hard-rock areas, there are large variations in groundwater availability even from village to village.

To improve the groundwater situation, it is necessary to recharge depleted groundwater levels. The techniques should be easy, cost-effective and sustainable in the long term. It should be possible for many of these to be adopted by individuals and village communities, and built with locally available materials and labour.

In India—pre-monsoon and post-monsoon—annual groundwater yields have been observed to exceed annual groundwater recharge, resulting in significant decreases in long-term groundwater levels.

The idea of using and managing groundwater in the aquifers is not new. Since the First Five-Year Plan, different government programmes have focused on recharge of groundwater. Recharging groundwater for sustainability of quality and quantity has become of critical importance.

Groundwater recharge is becoming increasingly necessary to ensure sustainable groundwater supplies to serving the needs of a growing population. Projects

OVEREXPLOITATION OF GROUNDWATER LEADS TO WATER-STRESSED BLOCKS IN POPULATED STATES OF INDIA

As per a Central Groundwater Board (CGWB) assessment, a comparison of 2004–14 data on assessed groundwater-exploited units (blocks, tehsils, talukas) in the states shows that the number of over-exploited units in the major states of the country, including Haryana, Rajasthan, Maharashtra, Delhi and Punjab, has increased.[1]

There has been sharp rise in the number of over-exploited groundwater blocks in states such as Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh. The amount of groundwater extraction in these states is more than the amount of recharge annually, resulting in declining water levels and stress on the resource.

An analysis of 2004 data of states such as Jharkhand and Bihar shows that these states did not have any over-exploited units in their districts. But an assessment of 2020 data shows overexploited units in these states as well as overusage of groundwater resources. In 2004, Bihar and Jharkhand had no overexploited units; in 2020 Bihar had seven overexploited units and Jharkhand had three (see *Table 1: Comparison of overexploited units in states of India* and *Graph 2: Increase in overexploited blocks in selected states of India*).

Table 1: Comparison of overexploited units in states of India

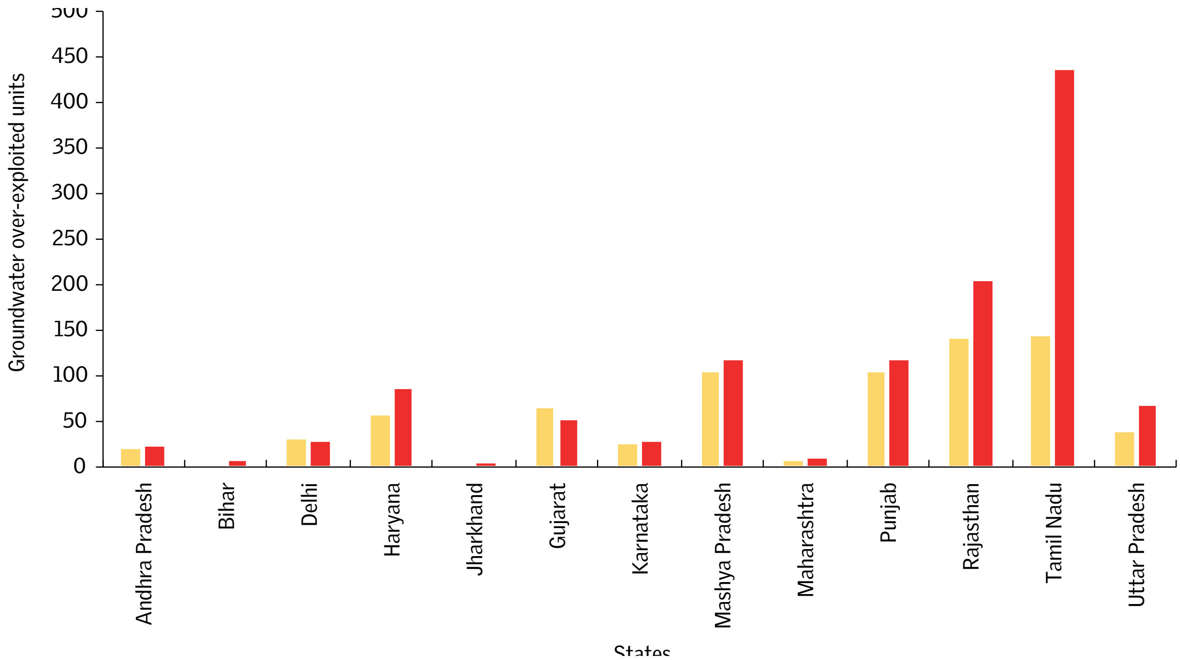
State	Total overexploited units	
	As on March 2004	As on March 2020
Andhra Pradesh	18	23
Bihar	0	7
Delhi	31	26
Haryana	55	85
Jharkhand	0	3
Gujarat	65	52
Karnataka	24	26
Madhya Pradesh	103	117
Maharashtra	7	10
Punjab	103	117
Rajasthan	140	203
Tamil Nadu	142	435
Uttar Pradesh	37	66

Source: Compiled from CGWB Data

around groundwater recharge can also provide multiple benefits, such as maintaining agricultural productivity, providing domestic water use and sustaining groundwater-dependent ecosystems (GDEs).

The benefits of groundwater recharge, which become evident only after at least a year or two, include the following:

Graph 2: Increase in overexploited blocks in selected states of India



Source: Compiled from Central Groundwater Board reports

- Enhancement of subsurface storage in water-scarce areas;
- Mitigation of evaporation loss;
- Improving the quality of groundwater by infiltration through the permeable media;
- Controlling soil erosion and flood and providing sufficient soil moisture even during summer months;and
- Promoting saving of energy due to reduction in suction and delivery head as a result of rise in water levels.

Forecasting conditions for groundwater recharge

Rainfall in India is largely limited to about three months in a year. Natural recharge of groundwater reservoirs is restricted to this period in a major part of the country. It is important to predict the suitable time and techniques for groundwater recharge based on rainfall pattern, intensity of rainfall, soil, geology, physiography and other related factors that aim at enhancing groundwater recharge in the post-monsoon period. This eventually results in enhanced sustainability of groundwater sources during the lean season.

In arid regions of the country, rainfall is in the range of 150–600 mm/year, with even less than 10 rainy days at some places. A major part of the precipitation is

UNDERSTANDING THE BASICS OF GROUNDWATER

Groundwater lies beneath the surface of the ground and fills pores in sediments and sedimentary rocks and fractures in other rock types. It is:

- Resupplied by slow infiltration of precipitation, and
- Accessed by wells

When there is precipitation (rain), water runs off of IMPERMEABLE surfaces, and it INFILTRATES PERMEABLE surfaces.

Origin of groundwater

a. Meteoric water is water derived from precipitation.
b. Connate water is water trapped in the pores of a rock during formation of the rock. Connate water is also described as fossil water.
c. Magmatic water is derived from magma. It is released into the atmosphere during a volcanic eruption.

Water table

- Subsurface zone in which all rock openings are filled with water is the saturated zone.
- Water table, also known as potentiometric surface, is the top of the saturated zone.
- Above the water table is an unsaturated region called the vadose zone (zone of aeration).

In India, groundwater is the major source of water for irrigation, drinking and domestic use. It is important to understand the consumption of groundwater at different administrative levels (village, block/taluka/tehsil and district levels). We can also forecast groundwater availability at the watershed or sub-watershed level.

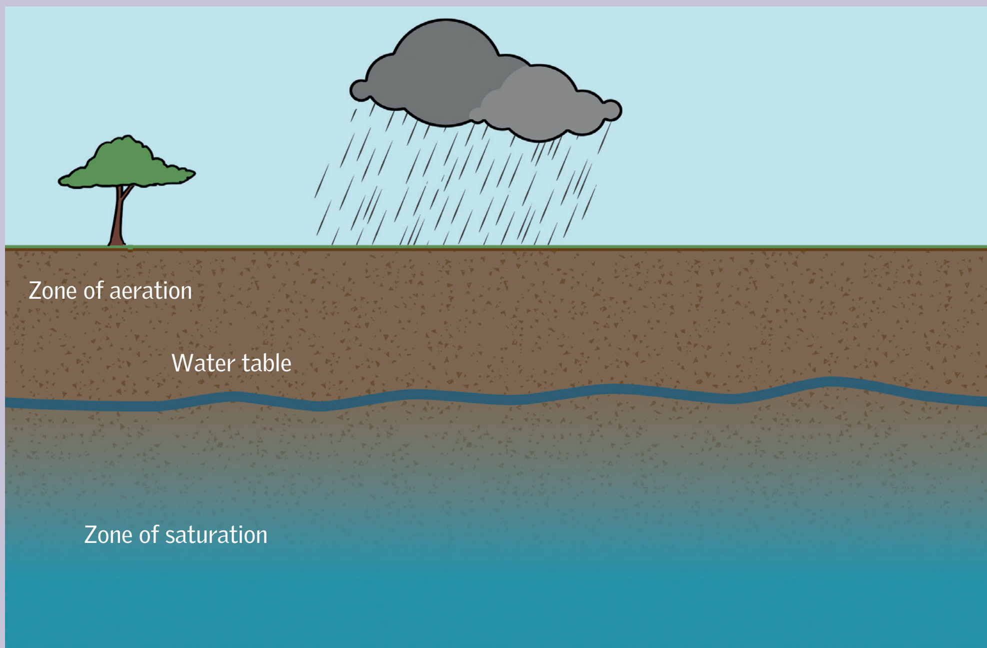
Studying groundwater levels in different years can also forecast declining or rising patterns. It is also important to understand the amount of recharge and the amount of exploration to see the water balance.

Water budgeting is an important tool to analyse total supply and demand at different geographical scales. It helps predict the demand–supply gap. Accordingly, solutions need to minimize the demand–supply gap for source sustainability. Water budgets provide a means to evaluate availability and sustainability of a water supply.

Forecasting groundwater recharge using traditional knowledge
Water harvesting is an age-old practice in India and was used by our ancestors for conservation and management of water. Traditional water-harvesting was very effective in facilitating the movement of water to the groundwater system. The practice was prevalent across the country using the local terrain and climatic knowledge to store the rainfall. Traditional water-harvesting methods, which were in vogue in arid and semi-arid areas of the country, have either been abandoned or become defunct in most cases. There is an urgent need to revive these methods.

In rural areas, ponds, streams and wells have traditionally been used as sources of water for drinking and other domestic uses. In recent years, bore wells, hand pumps and small water-supply schemes have almost replaced these traditional sources of water. Yet, in many rural habitations, for various reasons, these sources have not been able to supply water to rural households round the year.

Figure 2: Representation of water table, zone of aeration and saturation



Source: Central Groundwater Board

One of the most popular traditional practices was rainwater conservation. Water from the rooftops would be collected during the rains and stored in tanks. Collection of roof water on a small scale from house roofs to meet immediate household needs is a traditional practice in some parts of India such as the Northeast states, Rajasthan and the eastern coastal areas of Tamil Nadu.

Management of surface and sub-surface water in the past aligned with the study of ecology and rainfall distribution in the country. The following are impactful traditional water-harvesting practices in different ecological regions of India (see *Map 1: Ecological regions of India*).

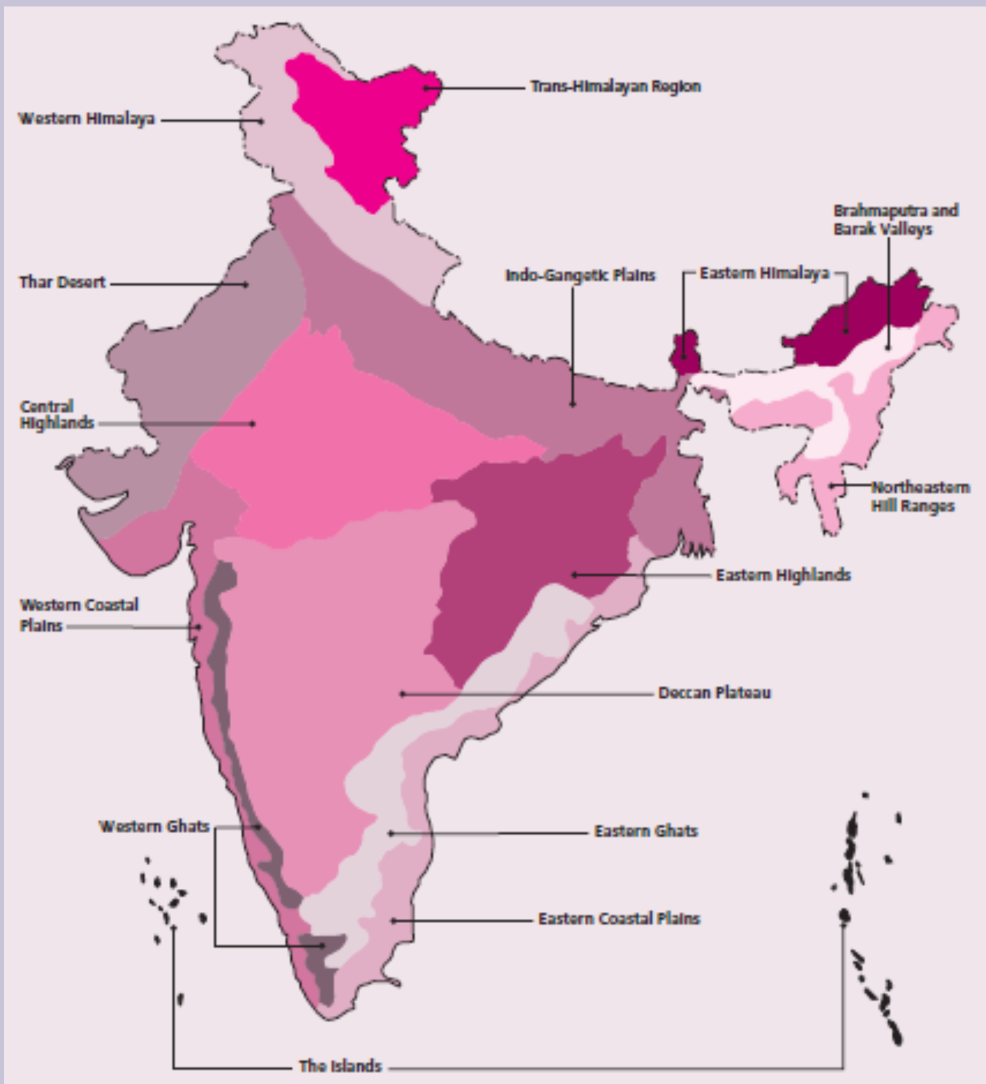
- In arid and semi-arid regions, where water in the streams are seasonal and scarce round the year, diversion channels—variously called zing in Ladakh, ahar in south Bihar and kere in Karnataka—were first directed into storage structures so that water could be used in the dry period for agriculture and for human and animal consumption. Not all storage structures, however, were river-fed or stream-fed.

- In the floodplains, people developed ingenious techniques to use devastating floodwater to irrigate their fields and also to fertilize them and control diseases such as malaria by using the fish in the floodwaters to eat away the mosquito larvae.

- In coastal areas too, where coastal tides would periodically turn river water saline and make it unsuitable for agriculture, people developed fascinating innovations. The khazan lands of Goa have systems that regulate the flow of high-salinity river waters, and thus control their impact on the productivity of rice agro-ecosystems and long-term soil fertility.

- In areas with good groundwater aquifers, rainwater is harvested with the help of dug wells. Various technologies using local materials to lift the water to irrigate the fields have been developed.

Map 1: Ecological regions of India



Source: Anil Agarwal and Sunita Narain (ed) 1997, *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*, Centre for Science and Environment, New Delhi.

received in three to five major storm events lasting only a few hours. The rates of potential evapotranspiration (PET) are exceptionally high in these areas, often in the range of 300–1,300 millimetre per year.[2] In such cases, the average annual PET is much higher than the rainfall, and the annual water-resource planning has to be done by conserving the rainfall by storing available water either in surface or sub-surface reservoirs. In areas where climatic conditions are not favourable for creating surface storage, recharge techniques have to be adopted for diverting most of the surface storage to groundwater reservoirs within the shortest possible time.

Rainfall in hilly areas is generally higher than in the surrounding plains. Most of the rainwater runs off the surface due to steep slopes. Springs are the major source of water supply for these areas. Rainwater harvesting and small surface-storages planned at strategic positions recharge springs and help in making them sustainable through the year.

From the aforementioned, we can see that revival of traditional water-harvesting systems for rainwater harvesting along scientific lines can go a long way in preventing a serious water crisis in the major part of our country. Based on typological ecological regions, suitability of the harvesting structures can be assessed for groundwater recharge (see *Table 2: Typology of traditional Indian water-harvesting systems*).

The amount of rainfall and number of rainy days at a given place determine the period for which water will be required for rainwater-harvesting systems. For example, places that receive rainfall only from the southwest monsoon (for three to four months) require water from rainwater harvesting systems for longer than Kerala and the Northeastern states. Also, in low-rainfall areas such as western Rajasthan and northern Gujarat, roof size could become a limiting factor as households in these areas may require water for an extended dry period of seven to eight months. Here, traditional water-harvesting systems make use of open lands adjacent to houses as catchments areas for domestic water-harvesting systems[3] (see *Table 3: Traditional water-harvesting and recharge practices in India*).

Identifying potential groundwater recharge zones

There have been continued efforts in India for development of groundwater resources to meet the increasing demands for water supply, especially in the last few decades. In certain high-demand areas, groundwater development has already reached a critical stage, resulting in acute scarcity of the resource.

Table 2: Typology of traditional Indian water-harvesting systems

Ecological regions	Systems for agriculture	Systems for drinking water
Hilly and mountainous regions	a. Diversion channels leading directly to agricultural fields (e.g. guhls and kuhls of the western Himalayas). b. The channels first lead into a storage structure so that water can also be used in subsequent dry periods (e.g. zings of Ladakh).	a. Natural springs were often harvested. b. Rainwater harvesting from rooftops. c. In the Northeast, spring water is often carried over long distances with the help of bamboo pipes.
Arid and semi-arid regions	a. Rain-fed storage structures, which provided water for a command area downstream (e.g. tanks). b. Stream or river-fed storage structures, sometimes built in a series, with overflow from one becoming runoff for the subsequent one (e.g. system tanks of Tamil Nadu, bandharas of Maharashtra, keres of Karnataka). c. Rain-fed storage structures, which allow runoff to stand over and moisten the fertile soil-bed of the storage structure itself, which is later used for growing crops (e.g. khadins of Jaisalmer district and johads of Alwar district in Rajasthan).	a. Groundwater harvesting structures like wells and step wells were built to tap groundwater aquifers (e.g. baodis of Rajasthan). b. Groundwater harvesting structures such as wells and stepwells were invariably built wherever they were possible, especially below storage structures such as tanks, to collect clean seepage for use as drinking water (e.g. several such structures found in the forts of Chittor and Ranthambhore). c. Rainwater harvesting from rooftops (e.g. tankas of Pali). d. Rainwater harvesting using artificially created catchments that drain water into an artificial well. Just about any land can be used to create such water-harvesting structures (e.g. kunds of Rajasthan). e. Special rainwater-harvesting structures that help keep sweet rainwater from mixing with saline groundwater and thus provide a layer of potable water (e.g. virdas of Kutch). f. Horizontal wells similar to the qanats of the Middle East to harvest seepage downhill slopes (e.g. surangams of Kerala). g. Dug wells

Ecological regions	Systems for agriculture	Systems for drinking water
Plains and floodplains	a. In the floodplains of major rivers, people built inundation channels that allowed floodwaters to be diverted to agricultural lands (e.g. flood irrigation system of West Bengal). b. In specific types of soil and cropping regions, people also store rainwater in the agricultural fields by bunding them (e.g. haveli system of Madhya Pradesh).	Dug wells
Coastal areas	a. Regulatory systems to control ingress of saline river waters, especially during coastal tides, and thus maintain crop productivity in coastal plains (e.g. khazan lands of Goa).	Dug wells

Source: Anil Agarwal and Sunita Narain (ed.) 1997, *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*, Centre for Science and Environment, New Delhi

Table 3: Traditional water-harvesting/water management and recharge practices in India

Region	Structure	Description	Areas
Trans-Himalayan Region, Jammu and Kashmir	Zing	Small tank-like structures used to collect melted glacier water with a network of guiding channels	Ladakh and Kargil area
Western Himalayan region Kashmir Valley to Uttarakhand region	• Kul • Naula • Khatri • Kuhl	• Water channels lined with rocks to collect melted glaciers water • Small ponds or wells to collect water from the by making stone walls • Carved structures of size 10 x 12 x 12 m^3 in hard-rock mountains • Surface channels diverting water from natural flowing streams	• Spiti Valley and Jammu • Hilly areas of Uttarakhand • Hamirpur, Kangra and Mandi (HP) • Jammu and Kashmir • Himachal Pradesh and Uttarakhand
Eastern Himalayas, Sikkim, Arunachal Pradesh, Darjeeling (West Bengal)	Apatani	The slope of the valley is terraced in to plots separated by earth dams supported by bamboo frames	Lower Subansiri (Arunachal Pradesh)
Northern hill regions, Assam, Nagaland, Manipur, Mizoram, Meghalaya and Tripura	• Zabo • Bamboo drip irrigation	• Pond-like structures located on high ridges runoff water from hilltop passes through terraces and collected in ponds • Bamboo pipes are used to divert perennial spring water from hilltop to irrigation field in the lower reaches	• Nagaland • Khasi and Jaintia Hills
Brahmaputra Valley	Dungs	Small irrigation channels linking paddy fields	Assam

Region	Structure	Description	Areas
Indo-Gangetic Plains	Dighi baolis	• Square/circular reservoir with steps • Step wells	
Thar Desert, western Rajasthan, Kutch region of Gujarat, parts of Punjab and Haryana	• Kundi • Kuis/beris • Baoris/bers • Jhalaras • Nadis • Tobas • Tanks • Khadin • Vav/vavdi • Bavoli/bavadi • Virdas • Paar	• Looks like an upturned cup nestling in a saucer • 10–12-m-deep pits dug near tanks to collect the seepage water • Community wells used for drinking needs • Rectangular tanks with steps used for religious rites • Ponds storing water during rainy season • Natural catchment with ground depression • Lined circular holes made in the ground • Built across the lower hill slopes • Traditional stepwells with a sluice constructed at the rim • Shallow wells in low depressions • Rainwater flows from the catchment at a common water-harvesting place and percolates into the sandy soil.	• Parts of Rajasthan and Gujarat
Central Highlands, Rajasthan, Gujarat, Madhya Pradesh	• Talabs/bandhis • Saza Kuva • Johads • Naada • Pat • Rapat • Chandela tanks	• Human-made or natural lakes • Open well with multiple owners • Earthen check dams • A small stone check dam across a stream or gully • Structures to store the water by diverting swift flowing hill streams • Percolation tank with a bund to impound rainwater flowing through a watershed • Constructed by stopping run-off in rivulet • Flowing between hills by erecting massive earthen embankment	Bundelkhand region Rajasthan and Madhya Pradesh
Eastern Highlands, Bihar, Madhya Pradesh, Odisha	Katas/mundas/ bandhas	Strong earthen embankment curved at either end built across drainage line.	
Maharashtra, Karnataka and parts of Andhra Pradesh	• Cheruvu • Kohlis • Bandharas • Phad • Kere • Ramtek model	• Lake-like structure • Water tanks • Small check dams/diversion weirs built across rivers • Community-managed irrigation system • Check-dam-like structures built across streams for irrigation • Network of groundwater and surface waterbodies connected through surface and underground canals	Chittoor, Kadapa districts of Andhra Pradesh, northwest Maharashtra, Karnataka

Source: Anil Agarwal and Sunita Narain (ed.) 1997, *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*, Centre for Science and Environment, New Delhi

Overdevelopment of the groundwater resources results in declining groundwater levels, shortage in water supply, intrusion of saline water in coastal areas and increased pumping lifts, necessitating deepening of groundwater structures. To tackle the dual problems of desaturation of aquifer zones and consequent deterioration of groundwater quality, there is an urgent need to augment the groundwater resources through suitable management interventions.

Recharge of groundwater has been accepted worldwide as a cost-effective method to augment groundwater resources in areas where continued overexploitation without due regard to their recharging options has resulted in undesirable environmental consequences.

The various steps and methodology to identify area-specific challenges and accordingly plan for interventions are discussed in the following.

Step 1: Need assessment (baseline survey)

Before planning any interventions for management and augmenting groundwater resources, a baseline survey is vital to identify challenges, scope and need for any project. A baseline survey is a study done at the beginning of a project to collect information on the status of a subject before any type of intervention can affect it.

Baseline studies also help us determine priority areas of projects with multiple objectives. Capturing the right information before intervention can show which aspects of the target population best align to which objectives. Baseline and end-line surveys are sometimes required by funding organizations or partners to ensure optimal use of their resources (see *Table 4: Guidelines and data requirement for need assessment*).

A baseline survey is also undertaken to understand attitudes of the community. The main aim is to address the gap. The survey acts as an accompaniment to the quantitative and qualitative data.

Step 2: Demarcation of problematic zones

The second step in planning a project is to demarcate the area where recharge is required. The project can be implemented systematically in case a hydrologic unit such as a watershed is taken for implementation. The localized scenario is, however, also taken into account to augment groundwater resources.

Table 4: Guidelines and data requirement for need assessment

Introduction	Under this we define the need for the interventions, setting the context and understanding the geography under which the following information is required: a. Location: including longitude and latitude and district (s), block (s), basin, sub-basin and/or watershed b. General climatic conditions of the district and scheme area in particular Type of climate such as: o Humid o Sub-humid o Arid o Semi-arid c. Rainfall: o Average annual o Rainfall distribution o Number of rainy days
Demographic information	a. Total population b. Total household
Socioeconomic indicators	a. Occupation: Farmer, labourer, business b. Migration and reason for migration c. Any other occupation
General description of topography and physiography	a. Elevation range (maximum, minimum and general) b. Landform such as: o Hilly o Plateau o Foothill zone o Valley slopes o Plain area o Sand-dune area o Delta region o Coastal plains
Key demand centres	To understand the requirement of water for different needs against the total availability. a. Agriculture o Cropping pattern o Area under different crops b. Size of land holding c. Area under irrigation o Surface water o Groundwater o Other source d. Water requirement o Irrigation o Domestic uses o Industry o Livestock o Other

Water availability	Computation of total water availability from different sources a. Water availability from surface-water sources for different uses; b. Details of water availability from various groundwater sources in the last five years; c. Net water balance for present and future scenarios; d. Highlighting the need for augmentation of water supply for: o Irrigation o Domestic and drinking o Other uses
Technical assessment	In the overall context of the groundwater management, the following technical details shall be discussed: a. Hydrogeological setup o Water-bearing properties of the aquifer; o Depth to water levels and seasonal fluctuations (pre-monsoon and monsoon); o Long-term water-level trends
Existing water source	a. Number of wells—open well, dug well and/or borewell o Number of functional wells o Number of abandoned wells o Quality of water o Use of water: domestic, drinking and/or irrigation b. Surface water—river, canal, stream or drain o Number of month water available o Quality of water o Use of water: domestic, drinking and/or irrigation c. Any other source such as pond, johar or other traditional harvesting structure
Existing interventions	Any water-harvesting or recharge structure o Type of structure o Number of structures o Year of construction o Current status: functional, dilapidated or broken If functional: benefits If abandoned: reason and year If broken: any plan for renovation
Need for recharge of groundwater—based on the survey	a. Quantification of water shortage o Quantification of water shortage for different uses o Period of shortages o Location of deficit areas b. Quality problem o Control of seawater intrusion o Dilution of chemical pollution due to natural causes c. Other issues o Control of land subsidence o Waterlogging
Institutional mechanism	Any water-user group, committee, beneficiary group If yes: role and composition of group If no: reason

Source: Compled by CSE

Recharge of groundwater is normally done in the following:
- Areas where groundwater levels are regularly declining;
- Areas where substantial amounts of aquifer have already been desaturated;
- Areas where availability of groundwater is inadequate in lean months;
- Areas where salinity ingress or other quality deterioration is taking place; and
- Areas where groundwater reaches 8 metre below ground level (mbgl) or deeper.

Step 3: Decision-making based on local hydrogeological setting

Groundwater recharge schemes are site-specific, and even replication of proven techniques is to be based on the local hydrogeological and hydrological conditions. The following information from local wells needs to be taken into consideration while planning schmes to manage and augment groundwater resources:
- The unsaturated thickness of rock formations occurring beyond 3 metre below ground level should be considered to assess the requirement of water to build sub-surface storage.
- The process of groundwater recharge should aim at saturating this entire unsaturated zone (also known as vadose zone).
- The upper 3 metre of unsaturated zone should not be considered for recharging since it may cause adverse environmental impacts such as waterlogging, soil salinity etc.

Step 4: Identification of source water and recharge area

After the challenges, problematic areas and potential zones have been understood, the next important aspect is assessment of availability of adequate water for recharge.

The following are the main sources that need to be identified and assessed for adequacy:
- Precipitation (rainfall) over the demarcated area;
- Large roof areas from where rainwater can be collected and diverted for recharge;
- Canals from large reservoirs from which water can be made available for recharge;
- Natural streams from which surplus water can be diverted for recharge without violating the rights of other users; and
- Properly treated municipal and industrial wastewater. This water should be used only after ascertaining its quality.

In situ precipitation is available at every location but may or may not be adequate for the purpose of recharge. In such cases water from other sources may be transmitted to the recharge site.

Assessment of the available sources of water would require consideration of the following factors:
- Quantity of water;
- Time for which the water would be available;
- Quality of water and pretreatment required; and
- Conveyance system required to bring water to the recharge site.

After identification of the source water to be made available for recharge and an assessment of whether the source is qualitatively and quantitatively suitable, the area for recharge needs to be demarcated on the basis of a need assessment. Localized schemes can also be taken up for the benefit of a household, community or village.

Step 5: Hydrometeorological study

The following four kinds of information on rainfall need to be gathered:
- Average annual rainfall: Average annual rainfall over 25–50 years gives an overall picture of the total amount of water that can be collected.
- Pattern of rainfall: The pattern of rainfall over different months indicates when there is rainfall, and whether it is for most or part of the year;
- Number of rainy days: The number of rainy days indicates whether it is better to store rainwater or to recharge it. If most of the rainfall is during a short span of time, it is better to recharge the aquifer.
- Peak rainfall intensity: Peak rainfall intensity over a period of 25–50 years determines the size of the storage or recharge structure. The size is calculated on the basis of the amount of water needed to be stored or recharged during the most intense spell of rain, which can range from fifteen to thirty minutes. Recharge structures need to be designed so that they are able to deliver peak intensity rainfall to the aquifer or store it temporarily during such intense spells.

Using data on rainfall and runoff coefficient

Rainfall and runoff constitute the major sources of water for recharge of groundwater. Rainfall is the primary source of recharge into the groundwater reservoir. For proper evaluation of source water availability, a thorough understanding of rainfall and runoff is essential. Collection and analysis of hydrometeorological and hydrological data play an important role in the assessment of source water availability for planning and design of recharge schemes.

UNDERSTANDING WATER BUDGET AND CALCULATING RAINWATER HARVESTING POTENTIAL

As a thumb rule, if you have 10 mm of rainfall over 100 square metre (sq. m) of roof area you will get 1,000 litre of water (volume = rainfall x area). However, there is some loss due to evaporation or absorption by catchment surfaces. The actual volume can be ascertained by determining the run-off coefficient of the catchment, which indicates the proportion of rainwater that can be harvested from the total rainfall.

How much rainwater can be collected?
Total volume of water = Area x run-off coefficient x rainfall

Area = Length x breadth = 20 m x 10 m = 200 sq. m

Run-off coefficient of roof = 0.8

Annual rainfall = 500 mm

1. Rainwater harvesting potential = 200 x 0.8 x 500 = 80,000 litre
2. Water demand for family of four consuming 540 litre/day = 540 x 365 = 197,100 litre/year
3. Water demand for family of four during the three driest months = 540 x 90 = 48,600 litre
4. Water demand for toilet flushing and gardening (yearly) at 180 litre/day = 180 x 365 = 65,700 litre

To arrive at the rainwater harvesting potential more accurately, daily or weekly rainfall data can be recorded. Once you have an idea of how much water can be harvested, match this against your water demand. This way, you can determine the size of the system as well as the level of water treatment required, with the budget taken into consideration. If it is not practical to meet all water needs for the entire year from rainwater harvesting, the water demand for the driest period or the period of acute water scarcity can be estimated to use rainwater to mitigate water scarcity.

Precise estimation of runoff is the most important requirement for the design of recharge structures of optimum capacity. Wrong estimation of runoff leads to the construction of oversized or undersized structures, which must be avoided.

Runoff is defined as the portion of precipitation (rainfall) that makes its way towards rivers or oceans as surface or subsurface flow. After the occurrence of infiltration and other losses from the precipitation, the excess rainfall flows out through the small natural channels on the land surface to the main drainage channels. Such types of flow are called *surface flows* (see *Chapter 5: Designing of different groundwater recharge structures* for calculation of rainfall intensity, depth and runoff for planning and designing recharge structures).[2]

Selecting priority interventions based on a criterion

For systems where harvested rainwater is used to recharge an aquifer, selection of the correct site is important. Information on the following must be collected before locating the site.

Aquifer: Find out depth of water level, thickness and nature of aquifer (confined or unconfined).

Rock: Note down the type of rock (massive, fractured, fissured, weathered or sedimentary).

Soil: Will the soil type allow water to percolate easily? To answer this, you have to know the soil type (is sand, gravel, silt, loam or clay?).

Physiography: Note whether the area is hilly, plains, coastal or desert.

A detailed hydrogeological study of the project area and also the regional picture of hydrogeological setting is necessary to know precisely the promising locations for recharge and the type of structures to be built for the purpose. Aspects to be considered for a recharge scheme include the following:

I. Types of aquifers

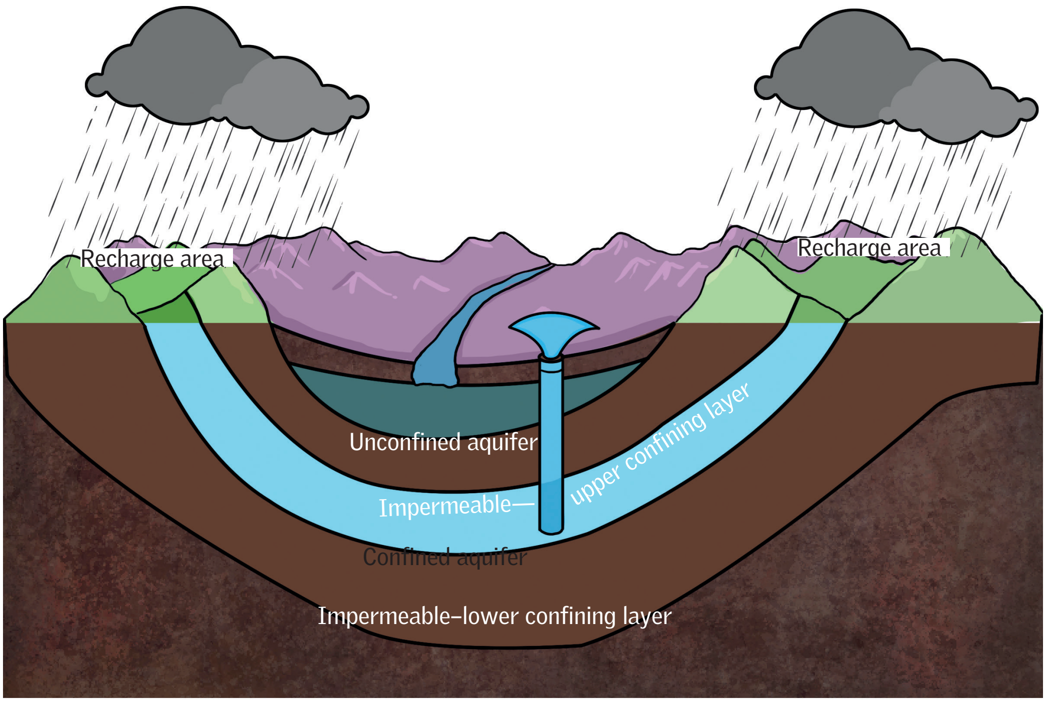
An aquifer is a saturated geological formation that contains and transmits "significant" quantities of water under normal field conditions (see *Figure 3: Representation of unconfined and confined aquifers*).

Aquifers are broadly classified into the following two types:

Unconfined aquifers: An aquifer whose upper boundary is formed by the water table, also known as phreatic aquifer. Rapidly recharged by rain or stream water infiltrating directly through the overlying soil.

Confined aquifers: An aquifer overlain and underlain by an impervious layer. Groundwater in a confined aquifer is under pressure and will rise inside a borehole drilled into the aquifer. It may be replenished or recharged by rain or stream water infiltrating the rock at a considerable distance from the confined aquifer.

Figure 3: Representation of confined and unconfined aquifers



Source: Central Groundwater Board

SUITABILITY OF AQUIFER FOR GROUNDWATER RECHARGE

The suitability of an aquifer for groundwater recharge depends mainly on the storage coefficient, availability of storage space and permeability. Very high permeability results in loss of recharged water due to subsurface drainage while low permeability reduces the recharge rate. To have a good recharge rate and to retain the recharged water for a sufficient period for use during lean periods, moderate permeability is needed.

- Older alluvium, buried channels, alluvial fans, dune sands, glacial outwash etc. are favourable places for recharge.
- In hard-rock areas, fractured, weathered and cavernous rocks are capable of allowing high intake of water.
- Basaltic rocks, i.e. those formed by lava flows, usually have large local pockets that can take recharge water.

To have information about the type of aquifer system and its suitability, it is better to procure data from state or district departments. The more micro-level the data, the better it is for demarcation of recharge area. In case the data is not available we need to do primary surveys to locate the potential zones.

II. Properties of rocks and soil types affecting recharge

Infiltration: Soil texture is determined by varying proportions of differently sized particles. The main types of soil textures are sand, loam, silt and clay.

Different soils have varying infiltration rates that affect recharge. Infiltration can be defined as the process of water entering into soil through the soil surface. The maximum rate at which water can enter soil at a particular point under a given set of conditions is called infiltration capacity. Infiltration capacity depends on many factors such as soil type, moisture content, organic matter, vegetative cover and season (see *Table 5: Infiltration rates of different types of soil*). Similarly, different rock types—such as porous rock, pervious rocks and massive rocks—affect the rate of infiltration (see *Table 6: Infiltration characteristics of rocks*).

Porosity: The percentage of rock that consists of *voids* or *openings*. The volume of empty space in a rock or sediment defines its ability to hold water. Porosity is also defined as the ratio of pore/void volume to total volume, i.e. the space available for occupation by air or water and is usually expressed in units of per cent (see *Figure 4: Porosity of rocks*). Different rock types have different rates of porosity (see *Table 7: Porosity of soil and rock materials*).

Table 5: Infiltration rates of different types of soil

Soil type	Infiltration rate (mm/hour)
Highly clayey soils	Below 2.5
Shallow soils, clay soils, soils low in organic matter	2.5–12.5
Sandy loams, silt loams	12.5–25.0
Deep sands, well-aggregated soils	Above 25

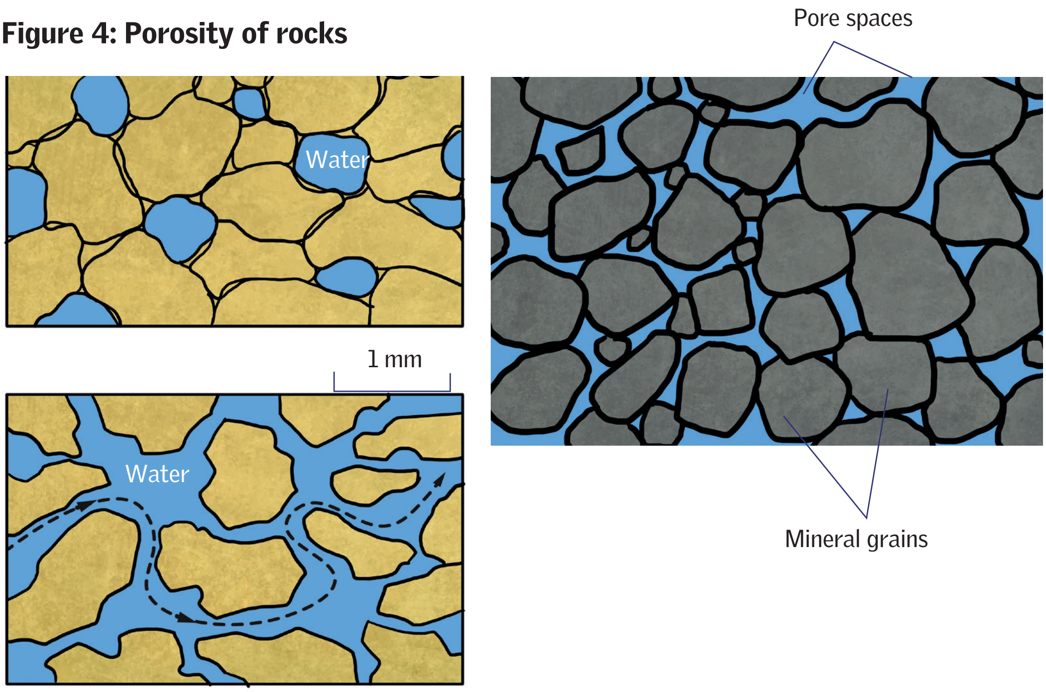
Source: Gita Kavarana and Sushmita Sengupta, 2013, *Catch Water Where It Falls— Toolkit on Urban Rainwater Havesting*, Centre for Science and Environment, New Delhi

Table 6: Infiltration characteristics of rocks

Parameter	Type of rock
Rocks that permit infiltration	Porous rocks (sandstone, chalk, shale) that have pores
	Pervious rocks (carboniferous limestone, marble) that have cracks or joints through which water can infiltrate
Rocks that permit some infiltration	Fractured, fissured, weathered (basalt, quartzite, gneiss)
Rocks that permit no infiltration	Massive rocks (granite, basalt) that are impervious

Source: Gita Kavarana and Sushmita Sengupta, 2013, *Catch Water Where It Falls—Toolkit on Urban Rainwater Havesting*, Centre for Science and Environment, New Delhi

Figure 4: Porosity of rocks



Total porosity in rocks *Effective porosity in rocks*

Source: Compled by CSE

Table 7: Porosity of soil and rock materials

Soil type	Porosity (%)
Gravel	25–40
Sand	25–50
Clay	40–70
Rocks	**Porosity (%)**
Limestone, dolomite	5–50
Karst	5–50
Sandstone	5–30
Shale	0–10
Crystalline rock	0–10

Source: Gita Kavarana and Sushmita Sengupta, 2013, *Catch Water Where It Falls— Toolkit on Urban Rainwater Havesting*, Centre for Science and Environment, New Delhi

USING SOIL AND LAND-USE DATA TO UNDERSTAND SUITABILITY OF GROUNDWATER RECHARGE ZONE

Soil and land-use conditions are of vital importance if recharge through surface spreading methods is contemplated in an area. Various factors such as the depth of soil profile, its texture, mineral composition and organic content control the infiltration capacity of soils.

- Areas with a thin soil cover are easily drained and permit more infiltration when compared to areas with thick soil cover in the valley zones.
- Soils with a coarser texture due to higher sand–silt fractions have markedly higher infiltration capacity as compared to clay-rich soils, which are poorly permeable.
- Soils containing minerals, which swell on wetting like montmorillonite etc. and with higher organic matter, are good retainers of moisture necessary for crop growth but impede deeper percolation.

Land use and extent of vegetation also control the infiltration capacity of soils. Barren valley slopes are poor retainers of water as compared to grasslands and forested tracts, which not only hold water on the surface longer, but also facilitate seepage during the rainy seasons through the root systems. Similarly, ploughed fields facilitate more infiltration as compared to barren fields.

Source: Central Groundwater Board

There are two types of porosity, including:

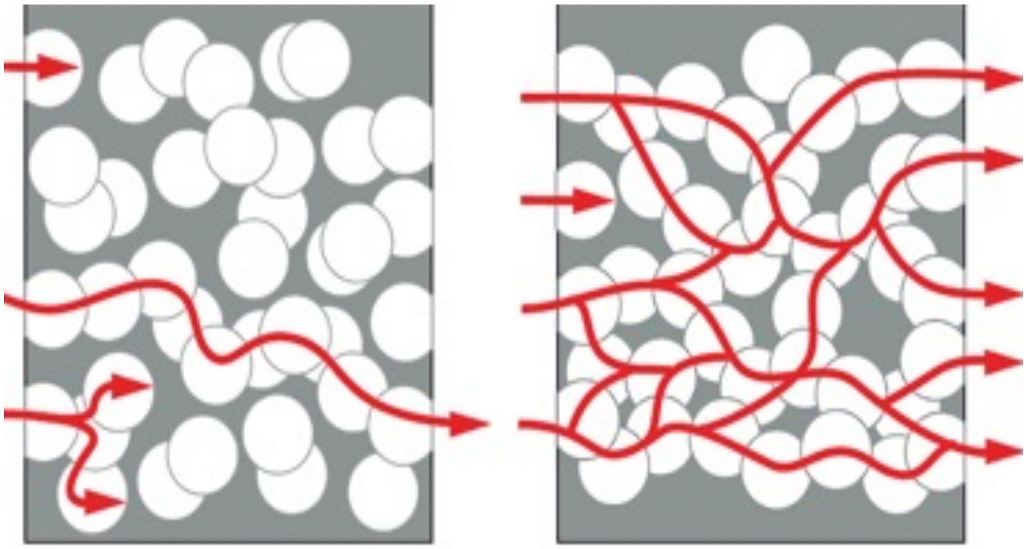
Primary porosity: Porosity that represents the original pore openings when a rock or sediment is formed.

Secondary porosity: Porosity developed in a rock after its deposition fractures, joints and solution opening.

Porosity is the void or space in the rock, but that does not necessarily mean that it will contribute to the flow of fluid. Therefore, it is important to know the effective porosity of the rocks which counts only interconnected pores and excludes isolated pores and pore volume occupied by water adsorbed. **Effective porosity is typically *less* than total porosity.**

Permeability: The ability of water or fluid to move through the material (soil/rock) is known as permeability. Also known as hydraulic conductivity, it may be also defined as the capacity of a rock to transmit fluid through pores and fractures. High permeable material allows water to flow readily. Water flows slowly through low permeability material. Material can be porous without being permeable, but it cannot be permeable without being porous. Hence, permeability is proportional to interconnectedness of pore spaces (see *Figure 5: Relationship between porosity*

Figure 5: Relationship between porosity and permeability



Good porosity, poor permeability

Good porosity, poor permeability

Source: Compled by CSE

PERMEABILITY DEPENDS ON

Sediments: Proportional to sediment size
- Gravel Excellent
- Sand Good
- Silt Moderate
- Clay Poor

Rock: Proportional to fracture size and number. Can be good to excellent.

Table 8: Permeability of soils

Type of soil	Permeability (cm/hour)
Sand	5
Sandy loam	2.5
Loam	1.3
Clay loam	0.8
Silty clay	0.25
Clay	0.05

Source: Gita Kavarana and Sushmita Sengupta, 2013, *Catch Water Where It Falls— Toolkit on Urban Rainwater Havesting*, Centre for Science and Environment, New Delhi

and permeability). Different soil types show different permeability, which is highest in the sand and lowest in clay (see *Table 6: Permeability of soils*).

- Most sandstones are porous and permeable.
- Granites, schists, unfractured limestones are impermeable.
- Shales tend to be porous but not permeable.

III. Physiography

Deals with the different topographic (terrain) settings. Therefore, physiographic factors within the area may tend to wield some degree of influence with respect to geospatial availability of groundwater (see *Table 9: Selection of rainwater-harvesting structures based on physiography*).

Matrix for planning for recharge or harvesting

Based on the assessment of the aforementioned criteria such as aquifer types, properties of rocks and soil, and physiographic characteristics, a decision is made on whether to make storage or recharge structures (see *Table 10: Decision matrix for selecting type of rainwater-harvesting structures*).

Table 9: Selection of rainwater-harvesting structures based on physiography

Parameter	Type of terrain
Areas more suited for storage	Hilly areas are more suited for storage structures as the recharged water is likely to travel down to the valley.
	Coastal areas: Where the groundwater is shallow and saline, more suitable for storage
	Desert areas: Low rainfall that may be absorbed by the thick sandy layer
Areas suited for storage or recharge	Plains are suited for both recharge and storage.

Source: Centre for Science and Environment, New Delhi

Table 10: Decision matrix for selecting type of rainwater-harvesting structures

Parameter	Type/condition	Recommended structure
Nature of aquifer	Impermeable, non-porous, non-homogeneous, hard rock areas	Storage
Depth of groundwater	More than 8 metre	Recharge and storage
Nature of terrain	Hilly, rocky or undulating	Storage
	Uniform or flat, alluvial and sedimentary	Recharge and storage
Nature of soil	Alluvial, sandy, loamy soils, gravel, silty, with boulders or small stones (kankar)	Recharge and storage
	Clayey soil	Storage
Nature of geological formation	Massive rocks (such as the Deccan Trap)	Storage
	Fractured, faulted or folded rocks, or comprising recharge and storage of weathered, jointed or fissured rocks	Recharge and storage
Nature of rainfall and monsoon	Number of rainy days are more, bi-modal monsoon, monsoon not intensive, uniformly distributed	Storage
	Uni-modal monsoon, rainfall available only for a few months	Recharge and storage

Source: Gita Kavarana and Sushmita Sengupta, 2013, *Catch Water Where It Falls—Toolkit on Urban Rainwater Havesting*, Centre for Science and Environment, New Delhi

QUALITY OF WATER RECHARGING GROUNDWATER

Before planning or identifying potential areas for recharge, the source water that will recharge the groundwater system needs to be ensured to be free from contamination or it will compromise the entire groundwater system.

Problems that arise as a result of recharge to groundwater are related mainly to the quality of rainwater available for recharge—the rainwater generally requires some sort of treatment before use in recharge installations. Problems also relate to the changes in the soil structure and the biological phenomena that take place when infiltration begins, thereby causing environmental concerns. Chemical and bacteriological analysis of source water and groundwater is therefore essential. Also, water to be used in recharge projects should be silt- free.

Water budget

A water budget is a measure of the amount of water entering and amount of water leaving a system. To maintain a balance in the ecological system, one must account for the incoming (source of water) and outgoing (water losses in the system) water resources. A water budget may be used to manage development of water resources within a region, and to ensure a sustainable supply of water over time.

An understanding of water budgets and underlying hydrologic processes provides a foundation for effective water-resource planning and management. Observed changes in water budgets of an area over time can be used to assess the effects of climate variability and human activities on water resources. Comparison of water budgets from different areas allows the effects of factors such as geology, soils, vegetation and land use on the hydrologic cycle to be quantified.

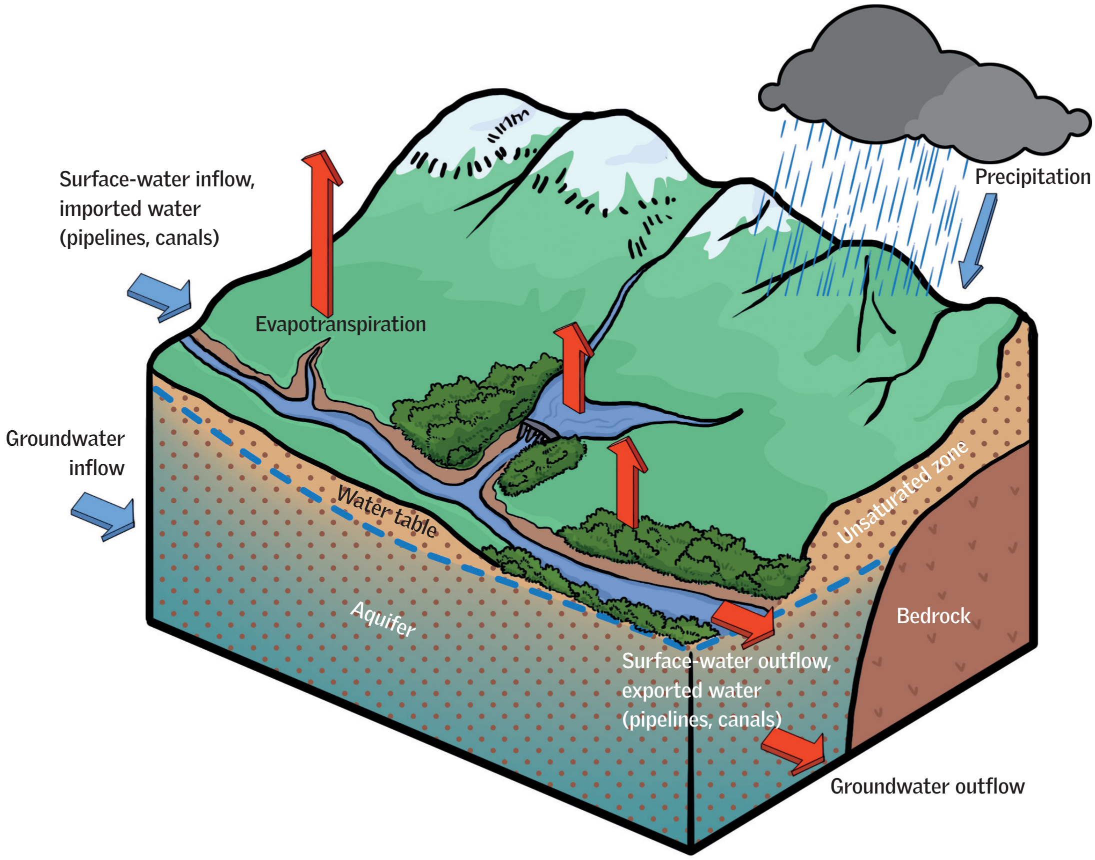
A water budget describes the various components of the hydrological cycle (see *Figure 6: Conceptual model of water budget*). The water budget typically includes:

- Precipitation (P)
- Evaporation (E)
- Evapotranspiration (ET)
- Surface runoff (SRO)
- Groundwater recharge (GWR)

To understand the water budget of a village it is important to understand whether the water balance is in surplus or deficit and accordingly a water management plan is undertaken.

Water Balance Identity can be defined by the following equation.

Figure 6: Conceptual model of water budget



Source: Central Groundwater Board

P (precipitation) = **E** (evaporation) + **T** (transpiration) + **SM** (soil moisture) + **SRO** (surface runoff) + **GWR** (groundwater recharge) (**Equation 1**)

Any precipitation happening in the area gets converted into evaporation, evapotranspiration, soil moisture, surface runoff and groundwater recharge as seen in equation.

The first three terms of the water budget equation—precipitation, evaporation or evapotranspiration (i.e. a combination of evaporation and transpiration by plants) and soil moisture—are natural processes that are largely unaffected by development. However, changes in land use can significantly affect surface runoff and groundwater recharge. If increase in groundwater recharge is planned, there should be provision to reduce the runoff. This can be done through various interventions on water harvesting and conservation, where the runoff can be checked and ample time allowed for water to percolate down the surface.

Precipitation (rainfall):
Precipitation, the primary water input to the hydrologic cycle, is evaluated for all water budget calculations. Precipitation data for a normal year should be used to evaluate the long-term impacts of a project. The precipitation data should be tabulated by month when evaluating the annual water budget. The rainfall data can be procured from the Indian Meteorological Department (IMD).

Evapotranspiration (PET):
Evapotranspiration is similar to evaporation, except that it applies to the combined effect of evaporation from the land surface and transpiration from growing plants. While evaporation is controlled exclusively by climatic factors, evapotranspiration also depends on the type of soil and plants. Evapotranspiration is most often determined by first computing the potential evapotranspiration (PET), which is the maximum amount of water loss if plants have a constant supply of soil moisture.

Surface runoff (SRO):
Runoff is the quantity of water discharged (runs off) from a drainage basin during a given time period. Runoff data may be presented as volume in acre-feet, as mean discharge per unit of drainage area in cubic feet per second per square mile, or as depth of water on the drainage basin in inches.

The term runoff refers to the overland flow of water after every rainfall or snowmelt. The overland flow starts when the rate of rainfall is greater than the rate of infiltration of the soil and increase in the amount of slope. Initially, runoff starts as small streams and water gets added from many such streams. Finally, all of these converge with a lake or stream or directly with seas.

The volume of water leaving through a river is known as river discharge. It is considered as precipitation returning to the sea.

Types of runoff:
- Surface runoff
- Subsurface runoff
- Base flow

a. **Surface runoff**: The portion of rainfall that enters a stream immediately after rainfall. It occurs when all losses are satisfied and rainfall continues and rate of rainfall [intensity] is greater than infiltration rate.

b. **Subsurface runoff**: The part of rainfall that first leaches into the soil and moves laterally, without joining the water table, to streams, rivers or the ocean. It is also referred to as inter-flow.

c. **Base flow**: The part of rainfall that after falling on the ground infiltrates into the soil, meets the water table and flows into streams, the ocean etc. The movement of water in base flow is very slow and it is therefore also referred to as delayed runoff.

Computing the water budget by calculating the water balance in a village (or any geographical scale) helps us infer whether the water scarcity is due to the restricted availability of the resource or its overuse for various needs (see *Figure 6: Steps to calculate water balance*).

To calculate the water balance there needs to be a proper understanding of the available water resource (surface water and/or groundwater) and water utilization data (see *Table 11: Data required to calculate water balance*) for drinking, domestic, agriculture, livestock and industrial requirements. Balance of available resources and demand of resource will give the budget.

Steps for data collection: Using data of Rewari district as an example

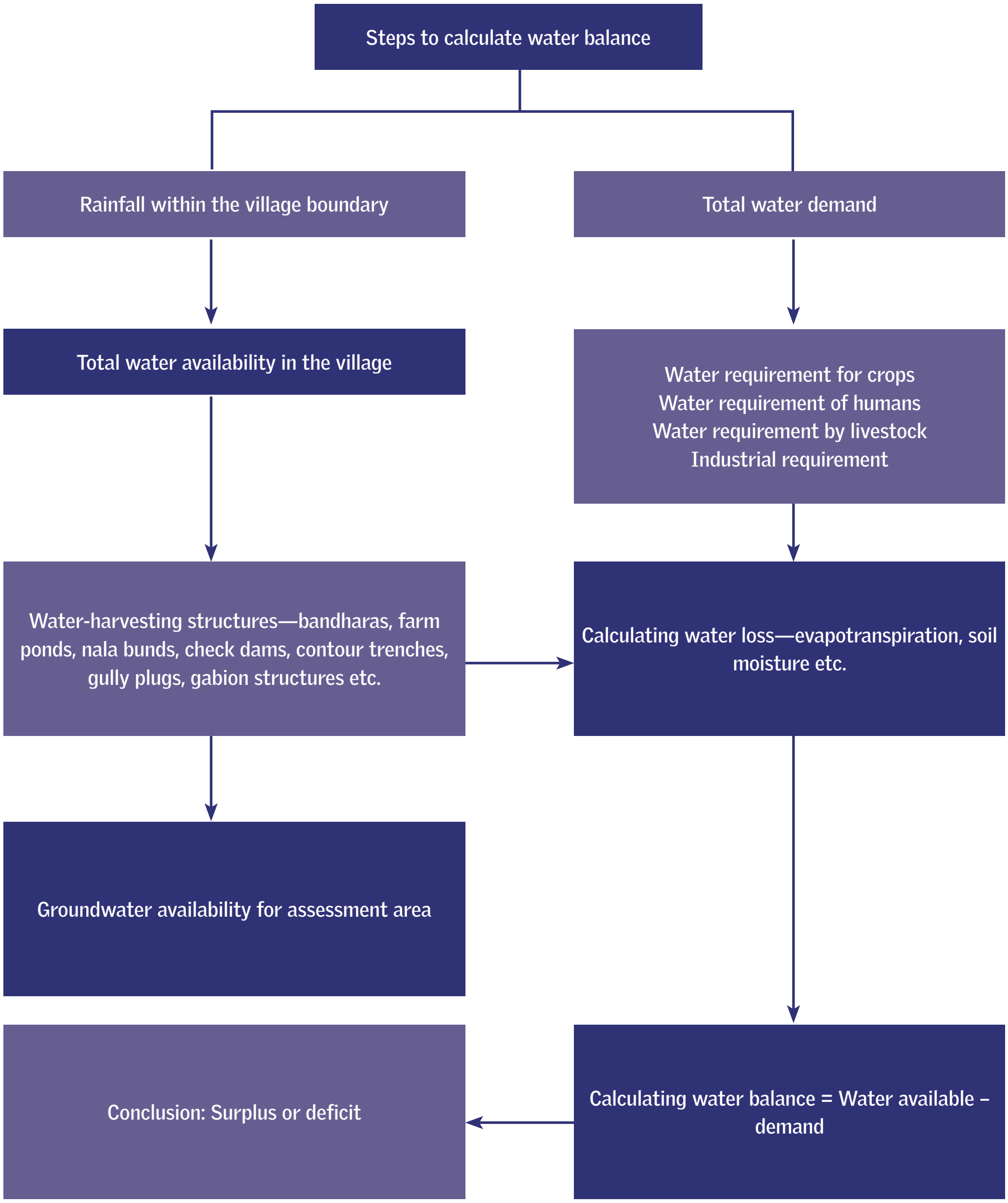
Step 1: Availability of water

i. Rainfall data: Rainfall data can be procured from the Indian Meteorological Department (IMD). However, if we need more micro and precise data at the village or hamlet level we can monitor rainfall by installing a rain gauge or Automatic Weather Stations (AWSs) and create data. The data can be monitored at the desired frequency daily, weekly, monthly or annually.

Table 11: Data required to calculate water balance

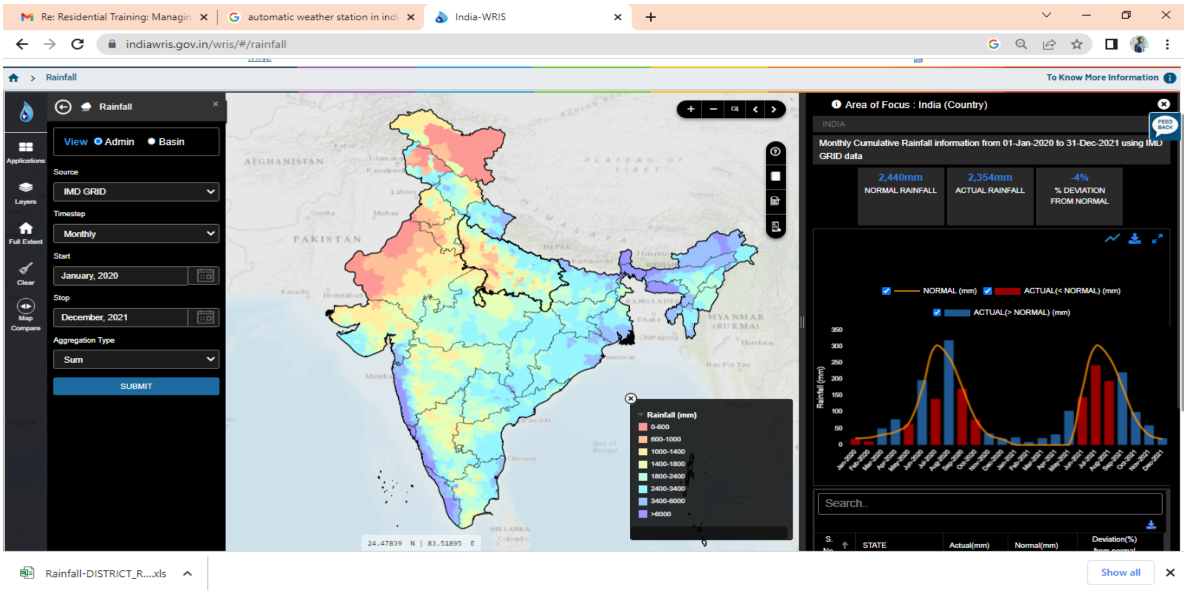
Water availability	Demand for water
Geographical area	Human population
Total rainfall	Livestock population
Evapotranspiration	Drinking and domestic requirement
Soil moisture	Type of crops taken
Total groundwater availability and draft for different uses	Industrial presence
Water-harvesting structures and their storage capacity	Other demands

Figure 7: Step-by-step calculation of water budget



Source: Compled by CSE

A rain gauge is simple, easy to install and inexpensive. The cost of a rain gauge in India starts from Rs 1,000. An AWS on the other hand needs proper installation and training is required for operating it and collecting data. Further, the cost of setting up an AWS is high. Data for rainfall can also be accessed at India the Water Resource Information System (WRIS), a Government of



Screenshot of interface of Water Resources Information System (WRIS) portal for rainfall dashboard

Source: https://indiawris.gov.in/wris/#/rainfall (as viewed on December 8, 2022)

Table 12: Rainfall for Rewari district, Haryana, 1989–2021

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Normal (mm)	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7
Actual (mm)	318.03	805.69	369.91	467.58	606.11	657.12	878.34	948.47	677.64	661.72	367.58	352.59

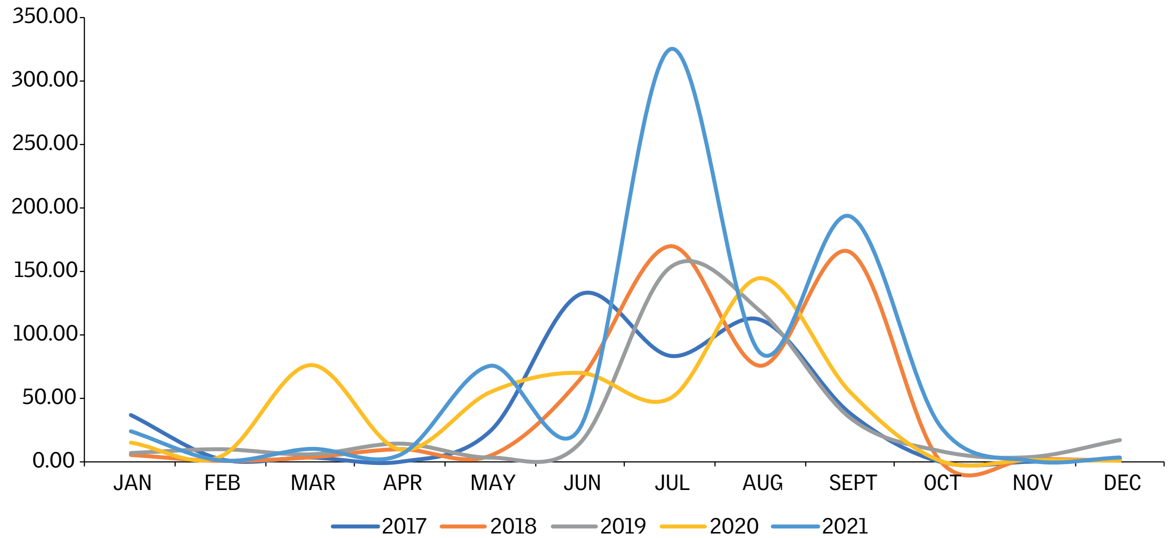
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Normal (mm)	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7
Actual (mm)	491.86	341.2	758.44	413.06	626.33	429.87	557.25	768.11	450.94	720.33	646.01	394.9

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021			
Normal (mm)	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7	561.7			
Actual (mm)	536.97	346.54	489.02	517.58	413.92	553.94	420.04	485.87	901.23			

Sources: Data compiled from Indian Meteorological Department; www.indiawris.gov.in

Graph 3: Monthly rainfall data for Rewari district, Haryana (2017–21)

Average annual rainfall for Rewari district is 557 millimetre (mm) (1989–2021). Peak rainfall months are July–September.



Source: www.mausam.imd.gov.in (as viewed on December 2, 2022)

India, Ministry of Jal Shakti, platform for data dissemination of surface and groundwater.

ii. Evapotranspiration (ET) data: This value gives combined data for evaporation

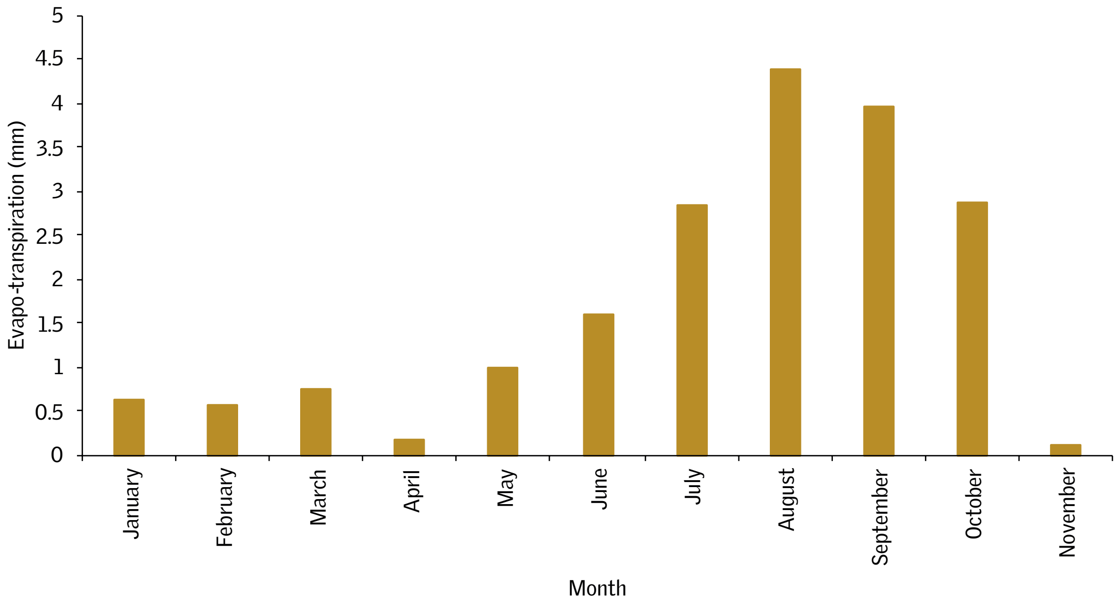
Table 13: National Remote Sensing Centre Data (NRSC) for Rewari district, Gurugram, 2021

Month	Value (mm)
January	0.62
February	0.56
March	0.74
April	0.19
May	0.98
June	1.59
July	2.84
August	4.38
September	3.96
October	2.86
November	0.12
Average	18.84

Source: Data compiled from India WRIS

Graph 4: Monthly evapotranspiration (ET) values

Annual ET value for Rewari district is 18.84 millimetre (mm). Peak ET months are May–October.



Source: Data from India WRIS (NRSC—Variable Infiltration Capacity Model)

and transpiration. The data can be procured from local departments monitoring it on a monthly or an annual basis. The data can also be procured from India WRIS.

iii. Groundwater data: This is also important data as groundwater is one the most used water resources for agriculture, drinking and domestic use, and industrial requirements.

It is important to understand the total draft of water for different needs. The data can be collected from Central Groundwater Board (CGWB), State Groundwater Board or if available from the district groundwater office. If the data requirement is for a micro level, say for a village or hamlet, the availability of data may be challenging and one needs to conduct a hydro-geological survey to collect the desired data. For example, block-level data of Rewari district was procured from India WRIS (see *Table 14: Groundwater data for Rewari district, 2017*).

Step 2: Water demand

i. Total population of the Rewari district: As per Census 2011, Rewari had

Table 14: Groundwater data for Rewari district, 2017 (values in million cubic metre)

Block/ mandal/ taluka	Annual replenishable groundwater resources (total)	Natural discharge during non-monsoon season	Net groundwater availability	Irrigation draft	Domestic and industry draft	Total draft	Stage of groundwater development (%)
Khol at Rewari	35.32	3.53	31.79	30.03	24.16	54.19	170
Bawal	86.56	8.66	77.9	48.21	2.8	51.01	65
Nahar	62.29	6.23	56.06	56.18	0.96	57.14	102
Rewari	74.81	7.48	67.33	63.98	4.52	68.5	102
Jatusana	85.28	8.53	76.75	53.64	6.64	60.28	79

Source: https://indiawris.gov.in/wris/#/GWResources (as viewed on December 8, 2022)

population of **900,332** of which male and female were 474,335 and 425,997 respectively.

It can be inferred that at Khol, Nahar and Rewari blocks have stressed groundwater as the annual draft is more the net groundwater availability. In Bawal and Jatusana on the other hand the annual draft is less then net groundwater availability. Overall, Rewari district falls in the overexploited groundwater zone, with the stage of groundwater development at 104 per cent.

Table 15: Total livestock population, Rewari district

Livestock	Number
Cattle	44,310
Buffalo	160,423
Sheep	5,384
Goat	24,127
Horse	260
Pony	16
Mule	248
Donkey	22
Pig	7,457
Camel	219
Dog	1,877
Rabbit	85
Total	244,428

Source: Department of Animal Husbandry and Dairying, Government of Haryana, 20th Livestock Census, 2019; http://pashudhanharyana.gov.in/livestock-census-0 (as viewed on December 8, 2022)..

ii. Total livestock population of Rewari district: 244,428 (see *Table 15: Total livestock population, Rewari district*).

iii. **Cropping pattern of Rewari district:** The major crops grown in Rewari district are mustard, bajra, wheat, cotton and barley.

Table 16: Cropping pattern of Rewari district

Crop type	Area (in hectare)
Mustard	71,000
Bajra	54,000
Wheat	46,000
Cotton	5,700
Barley	1,300

Source: https://agricoop.nic.in/sites/default/files/Rewari_Final-25-06-11.pdf (as viewed on December 8, 2022).

Steps 3: Calculation of water balance

Water availability

i. Volume of water collected in the Rewari district after rainfall: As per records for precipitation for 2021, the annual rainfall in this region is **557 mm.** Total geographical area of the district is **1,594 square kilometre (sq. km).**

First, we need to calculate all values to the same unit. Here rainfall is in mm and area is in sq. km. We convert the data unit to metre. So,

Annual rainfall (m) = 0.557

Geographical area (square metre) = 1,594,000,000

Total volume of water precipitated in the village = Average annual rainfall * Area of village
= 0.557 * 1,594,000,000 = 887,858,000 cubic metre (m^3)

Water loss

a. Surface runoff (SRO) = C * R * A (C = average coefficient of runoff, R = rainfall, A = Geographical area
SRO = 0.5 * 0.557 * 1,594,000,000 = **443,929,000** cubic metre

b. Evapotranspiration (ET)	=	0.01884 m
Volume of evapo-transpiration	=	Geographical area * ET
	=	1,594,000,000 * 0.01884

= 30,030,960 cubic metre

Considering loss as runoff, evaporation, transpiration

Available water = Precipitation – Losses

= 887,858,000 – 30,030,960

= 857,827,040 cubic metre

So total annual volume collected is 857,827,040 cubic metre (m^3) per year (as per 2021 data assessment).

Water demand

i. **Annual domestic water requirement**: According to Census 2011, the population of Rewari district was **900,332** of which 474,335 were male and 425,997 female. Total number of households in Rewari district was 13,980.

   As per ISI standards for communities with population more than 100,000 and with full flushing system, water supply through house service connection is 150–200 litre per household per day (lphd). By these standards, total annual domestic water requirement is as follows:

   200 (litre) * 900,332 (population) * 365 (days)
   = 65,724,236 cubic metre

Total annual domestic water requirement is 65,724,236 cubic metre (m^3) per year.

ii. **Annual livestock water requirement:** The total annual requirement of livestock and human was calculated on the basis of the standard water requirements of animals and humans given by the Food and Agricultural Organization (FAO) and ISI (Indian Standards) (see *Table 17: Water requirement for livestock*).

Table 17: Water requirement for livestock

Total water requirement for livestock is 5,072,288 cubic metre (m^3) per year

Livestock	Number	Litre per day (as per FAO and ISI)	Litre per annum
Cattle	44,310	8	129,385,200
Buffalo	160,423	83	4,860,014,785
Sheep	5,384	6	11,790,960
Goat	24,127	6	52,838,130
Horse	260	49	4,650,100
Pig	7,457	5	13,609,025
Total water consumption			5,072,288,200

Source: Food and Agricultural Organization

iii. **Annual crop water requirement:** Crop water requirement can be calculated as:

Area (in metre square) * delta (in metre for each crop type)
Delta is the standard for each crop which suggests the amount of water.
For example, for mustard (if the area is in hectare or acre or any other unit, convert it to square metre first.)
Area = 71,000,000 * 0.4 = 28,400,000
Total water requirement for mustard crop is **28,400,000 m^3** (see *Table 18: Calculation of crop water requirement, Rewari district*).

A comparison between water availability and water demand will give us the water budget (water balance).

According to the calculation for water availability in Rewari district and total calculation of demand, the water balance works out to 11,730,516 m^3 (surplus) after considering basic consumption. This implies that there is scope for more utilization of water to increase crop production through crop diversification in the agricultural and horticultural sectors.

Table 18: Calculation of crop water requirement, Rewari district

Crop type	Area (in hectare)	Delta (in m)	Crop water requirement (CWR) (m^3)
Mustard	71,000	0.4	28,400,000
Bajra	54,000	0.35	189,000,000
Wheat	46,000	0.5	230,000,000
Cotton	5,700	1.2	68,400,000
Barley	1,300	0.3	3,900,000
		Total crop water requirement	775,300,000

Total crop water requirement is 775,300,000 m^3.

Table 19: Water budget, Rewari district

Total water availability (m^3)	Total water demand (m^3)
857,827,040	(A) For domestic = 65,724,236
	(B) For livestock = 5,072,288
	(C) For irrigation = 775,300,000
Total availability	Total demand = A + B + C
= 857,827,040	= 846,096,524
Water balance = Total availability – Total demand	857,827,040 – 846,096,524 = 11,730,516

Source: Crop data was collected from the panchayat office, talathi office or local agriculture university or institutions and standards were taken from the Food and Agricultural Organization (FAO).

If the water balance works out to be in deficit, two options can meet the demand. First, more water sources have to be created in the area—construction of water-harvesting and conservation structures can increase annual water availability. Alternatively, if there is no scope for development of water infrastructure, demand-side management or regulation has to be practised. For example, in agricultural demand, modern irrigation techniques like the drip and sprinkler systems can be used instead of flood irrigation. In household activities, greywater generated from homes can be used in kitchen gardens rather than freshwater for irrigation; reuse of water at the domestic level shall be practised in order to meet the water demand.

(*The calculation of water budget is meant to simply illustrate the calculation and thus some hypothetical data has been used. For actual calculation, data from authentic sources shall be fetched and used [see* Table 20: Format for calculation of water budget])

Table 20: Format for calculation of water budget

Name of village				
Block				
District				
Latitude				
Longitude				
Annual average rainfall				
Area of village				
Population				
Livestock				
Small ruminants				
Agricultural land				
Barren land				
Waste land				
Habitat area				
Number of households				
Number of schools				
Anganwadi				
Government buildings				
Demand calculation				
Cropping details (i)				
Season	Name of crop	Area	Delta	CWR

Kharif				
Rabi				
Horticulture				
Others				
Subtotal (a)				
Human demands (ii)				
Category	Number	Average requirement/day		Annual requirement
Population				
Schools				
Government buildings				
Subtotal (b)				
Other demands (iii)				
Category	Number	Average requirement/day		Annual requirement
Subtotal (c)				
Total demand A = (a + b + c)				

Supply calculation				
Details of water structures (i)				
Name of source	Number	Storage capacity	No. of refills/year	Annual capacity

Surface water source				
Subtotal (d)				
Groundwater source				
Subtotal (e)				
Other sources				
Subtotal (f)				
Grand total (B) = (d + e + f)				

Total demand (A)	(cubic metre)
Total supply available (B)	(cubic metre)
Difference (C = A – B)	(cubic metre)

Source: Compiled by CSE

Need for monitoring groundwater recharge

The objective of water-level monitoring is to study the impact of recharge on the natural groundwater system through various water-conservation and harvesting measures. Interventions planned for groundwater recharge need to be monitored at regular intervals to assess the actual storage created in the structures, period of impounding, capacity utilization of the structure, rate of percolation and siltation problems if any.

Monitoring of groundwater is more challenging than monitoring of surface water (river and lakes)—initial investments (e.g. drilling a borehole) are larger, spatial representativeness of monitoring points (due to hydrogeological heterogeneity) is smaller and assistance of remote sensing (helpful for surface-water observations) is limited.

Monitoring of groundwater can serve the following objectives:

- Detect and evaluate changes in groundwater quality and quantity;
- Establish base-level background values of groundwater parameters;
- Monitor changes in groundwater regime over time and space;
- Evaluate the impact of degraded water quality and decline in water levels to prepare remedial action plan; and
- Set up surveillance systems
  (see *Chapter 6 for details on monitoring procedures*).

Chapter 3: Locating potential zones for groundwater recharge using advanced tools

- Participatory rural appraisal brings communities together to assess the problems of the village and prioritizes them to manage resources efficiently.
- Geospatial technology provides the ability to make decisions for planning of groundwater recharge.
- Superimposition of thematic maps, e.g. geomorphology, drainage and land use land classification, help to identify suitable recharge structures in accordance with the terrain, geology and hydrogeology of the area.

Chapter 2 describes how to decide on the type of groundwater recharge structure based on factors such as soil, geology, condition of groundwater, physiography and rainfall distribution. This chapter will tell us how to locate potential groundwater recharge zones in a watershed.

A watershed is defined as any surface area from which rainfall is collected from higher reaches and drained through the lower reaches or valleys. The part where rainfall is collected is the catchment of the watershed.

Prioritizing community knowledge

The success of any programme or scheme lies in the hand of communities. A community is a heterogeneous or homogeneous group working for a common interest. Communities can be at the village, city or town level. Self-help groups, water-user associations, farmers group etc. can also be considered as communities. Communities play a vital role in managing water in rural areas. Traditional wisdom has helped communities manage water resources since the earliest civilizations.

Different structures for water conservation and rainwater harvesting have been built since times immemorial. Entire villages depended on these structures for their water needs. Chandeli tanks in the Bundelkhand region, khadins and tanka in Rajasthan, dhaula and dhara in Himalayan regions, bandharas in Maharashtra and Karnataka, ponds in Madhya Pradesh and Chhattisgarh and many other structures were built to ensure water security in villages. The traditional knowledge of diverting river water and floods to use in agriculture also solved water-related issues in rural India. Communities have harvested water for their use in many ways in different parts of India and the world. Various water-harvesting structures have been discovered dating back to medieval and modern times in several countries. In India, the Harappan Civilization was known to have preserved water for domestic and agricultural use.

To identify groundwater recharge zones, it is important to use the knowledge of communities. This is because communities in villages are well versed on the physiography, drainage, soil, rainfall pattern and availability of water in wells. Knowledge and experiences can be utilized to locate groundwater recharge zones; when this is juxtaposed with site-specific technological options, concrete decisions on groundwater recharge zones can be made.

Various methods have been adopted to organize communities and engage them in assessment of groundwater sources and recharge zones. Formation of different community groups such as Water User Groups (WUGs), self-help groups (SHGs), Village Water and Sanitation Committees (VWSCs) and Watershed Committees (WCs) have helped in securing water for villages through traditional knowledge.

One of the most popular methods of assessing resources in a village is the Participatory Rural Appraisal (PRA). This method is used to engage the community in listing issues related to water management in the village and possible solutions. Every section of the village population represents its water-related issue. Without involving every group from different socioeconomic backgrounds, water-related problems cannot be solved.

Women should have equal participation as men in every community group. This is because women are key stakeholders when water is the subject of discussion. Water is a women-centric issue as it is used in most household work, and women bear the prime responsibility of fetching and providing water for domestic use. They are the water managers of every unit of society.

There are various ways to assess rainwater-harvesting potential and identify potential recharge zones in any area of interest. Here our focus is on planning of villages where communities and technologies are used together in assessing groundwater recharge potential.

Two methods that can be used to assess rainwater-harvesting potential and identify recharge zones are:

1. Participatory rural appraisal, and
2. Use of advanced technologies (remote sensing and GIS)

Participatory rural appraisal

Communities should participate in watershed management schemes in the village from very beginning. Local communities have deep knowledge on the geography, geology, rainfall and runoff, and their impact thereafter.

From the beginning of the planning phase of a scheme, a participatory rural appraisal (PRA) is carried out with the help of rural communities. The communities help to map issues around water management and possible solutions within the village.

There are various tools for conducting PRA. Depending upon the type of problem, a specific set of tools can be used.

Tools used in participatory rural appraisal

Participatory rural appraisal (PRA) uses several tools to assess problems in a village or watershed and to prioritize the problems. The following are some of the tools.

a. **Transect walk:** One of the most important tools of PRA, transect walk is carried out with community members throughout the village to map the important resources such as land, drainage, forest, habitations, water resources as well as the entire terrain. The route, existing landmarks and available resources etc. are mapped as one moves from one corner of the village to the other.

b. **Social mapping:** Social mapping is done to locate habitations of the village. The villagers create this map themselves. From the map, one can determine the number of households and their spread in the village for help in planning the network of water supply and roads and locating street lights.

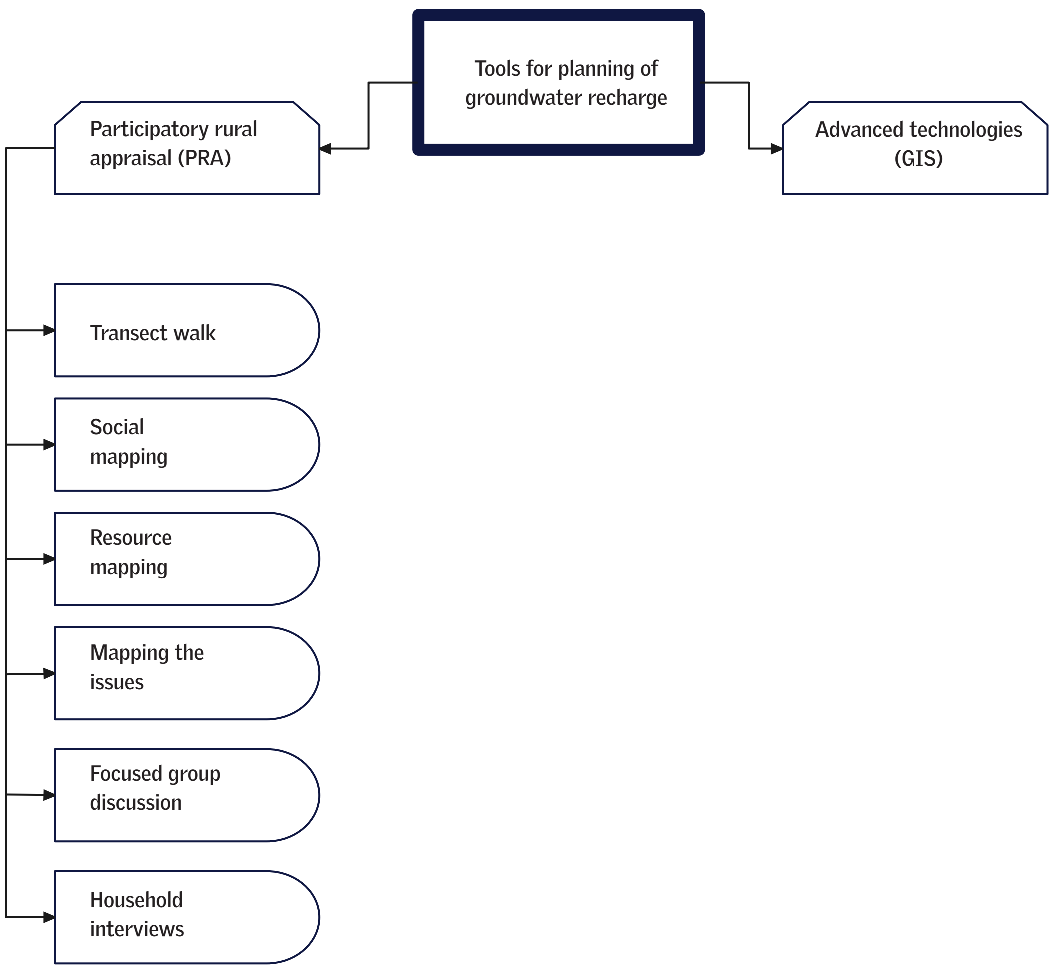
c. **Resource mapping:** The objective of resource mapping is to locate all the water resources, land use land cover, primary health centres, commercial centres etc. and other related resources. Just like a social map, a resource map is also created by villagers themselves.

d. **Mapping the issues**: In this activity, the community writes their problems on pieces of paper cut into circles of different sizes. The bigger the problem, the bigger is the paper. Seven to eight concentric circles with different diameters are drawn on the ground. The sizes of the diameters of the concentric circles are proportional to each other. For example, if the smallest circle has a diameter of 2 meter, four to five concentric circles with diameter in multiples of 2 are drawn subsequently.

The pieces of paper are arranged on the concentric circles. The papers that have problems to be tackled on priority are placed at the centre of the circle. Thus, different issues and prioritization are given a diagramatic representation (by a Venn diagram).

e. **Focused group discussion:** The objective of a focused group discussion is to bring out glaring problems of the communities or village. For this, discussions are held with the communities. The anchor of this discussion may be an external agency, panchayat official or any community member responsible for bringing change in the village. A structured questionnaire is developed before this activity is carried out.

Figure 8: Tools for planning of water conservation



Source: Compiled by CSE

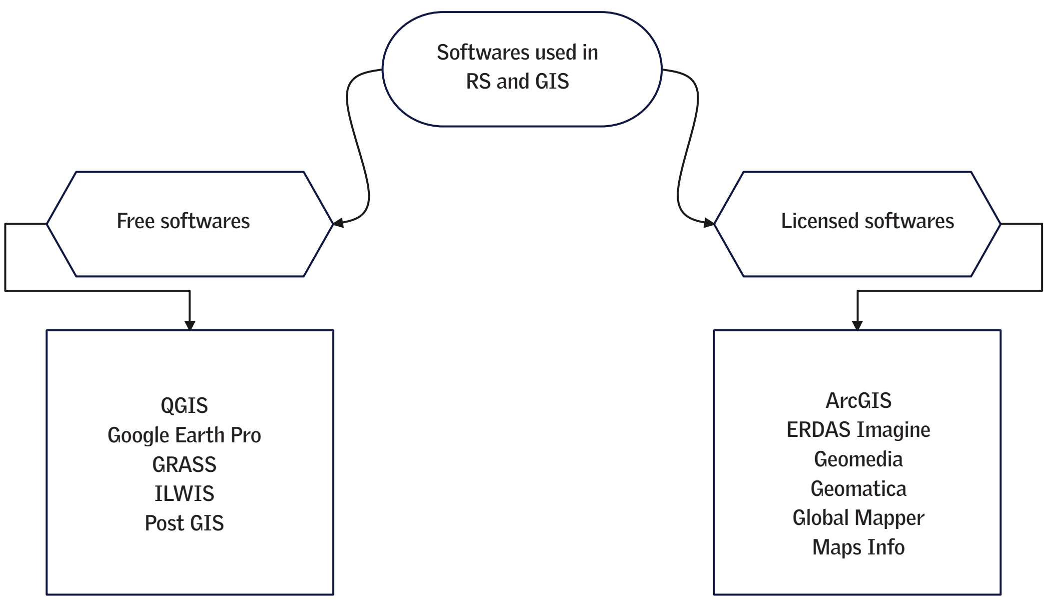
f. **Household interviews:** Interviews at the household level may identify problems at the household as well as at the village level. A questionnaire similar to that for a focused group discussion is prepared for the interviews.

Use of technology for assessing groundwater recharge potential

In Chapter 2, we referred to the traditional water-harvesting structures as solutions to water crises in villages. This chapter deals with some modern tools and technologies that can be used in addition to traditional knowledge for increasing groundwater recharge.

To make any plan for water conservation in a village, communities helps in understanding the resources and problems through different methods as discussed in the previous section. Modern technologies such as remote sensing (RS) and Geographical Information System (GIS) help in planning of groundwater recharge. The historical imagery obtained from softwares such as Google Earth Pro explains changes in habitation, terrain/physiography, land use land cover, and mapping of various resources, e.g. drainage pattern, erosion, groundwater prospects, lineaments, agriculture, salinity etc. This data can be integrated together using different softwares to arrive at a decision matrix and plan for groundwater recharge systems.

Figure 9: Softwares used in remote sensing and GIS



Source: Compiled by CSE

Different softwares of GIS are available in the market, some of which are free and some priced (see *Figure 9: Softwares used in remote sensing and GIS*).

In this chapter, we will focus on the use of free softwares, which have almost all the features of customized or licensed softwares. The most popular among the free softwares includes Quantum GIS (QGIS) and Google Earth Pro, which serve the purpose of identifying potential groundwater recharge zones and for rainwater harvesting.

The data required for analysis of recharge systems is available on public web portals such as Bhuvan, United States Geological Survey (USGS) and Geological Survey of India (GSI). These portals can be accessed to get data like Digital Elevation Model (DEM)—described in the following section—lineament, groundwater reserves, geology, erosion etc. and are superimposed with each other to locate groundwater recharge systems.

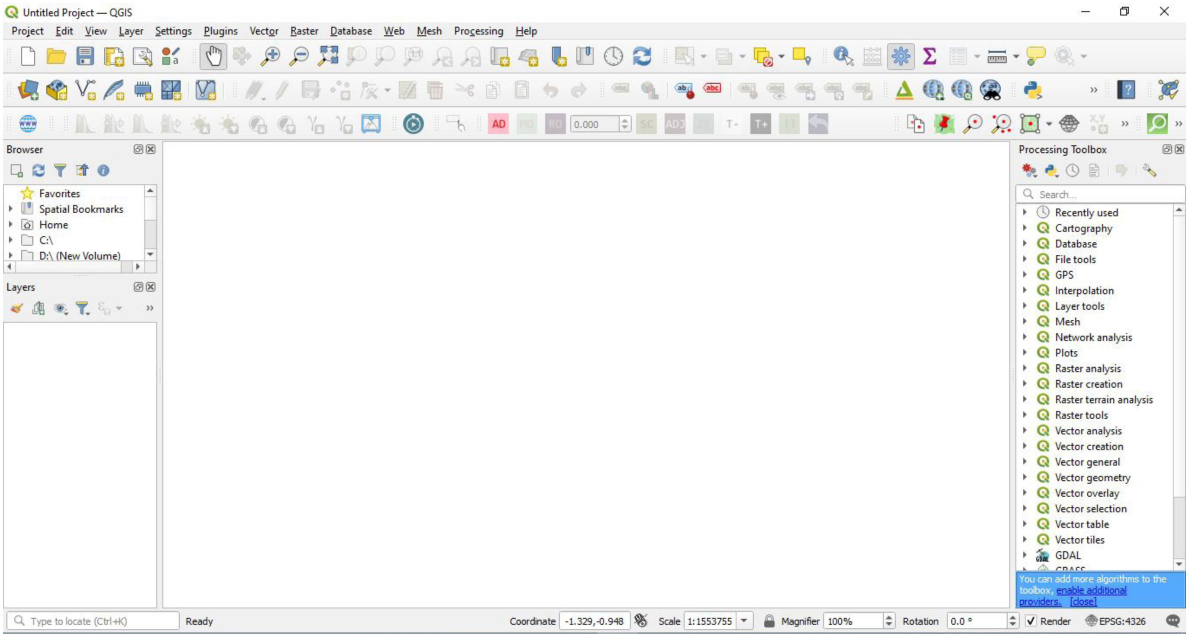
The following is a brief description of these softwares:

a. **QGIS:** Quantum Geographic Information System, abbreviated as Quantum GIS or QGIS, is a free software used for various spatial analyses and cartography. It is one of the best softwares available for free. QGIS has all the features and tools for effective analysis of all kinds of maps.

   Two types of file formats are created under GIS applications: raster (file formats in the form of pixels) and vector (file formats in form of a point, line and polygon). These file formats are imported to QGIS as layers

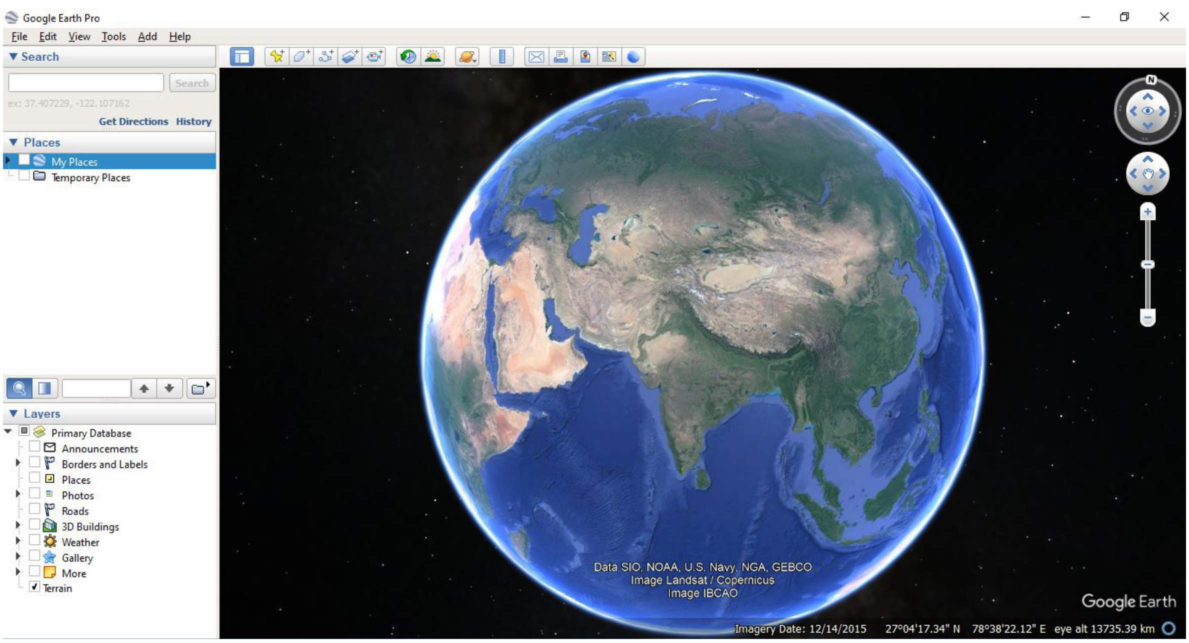
   The raster and vector layers are imported to the "Layers Panel" on the left side of software window to perform further operations. The icons below the "Menu" bar are shortcuts to the processing tools, which can also be accessed from the "Processing toolbox" panel on the right side of software window. The software is easy to use and can be used with any operating system like Microsoft Windows, Linux, MacOS or Unix (see *Figure 10: Interface of QGIS*).

b. **Google Earth Pro:** Google Earth Pro, a Google tool, is a user friendly and popular GIS tool, used for locating a place, measuring and mapping of resources. The tools of Google Earth Pro enable creating and superimposing multiple layers of raster and vector files, which help in understanding the potential locations of groundwater recharge and rainwater harvesting.



Screenshot of interface of QGIS

Source: QGIS software



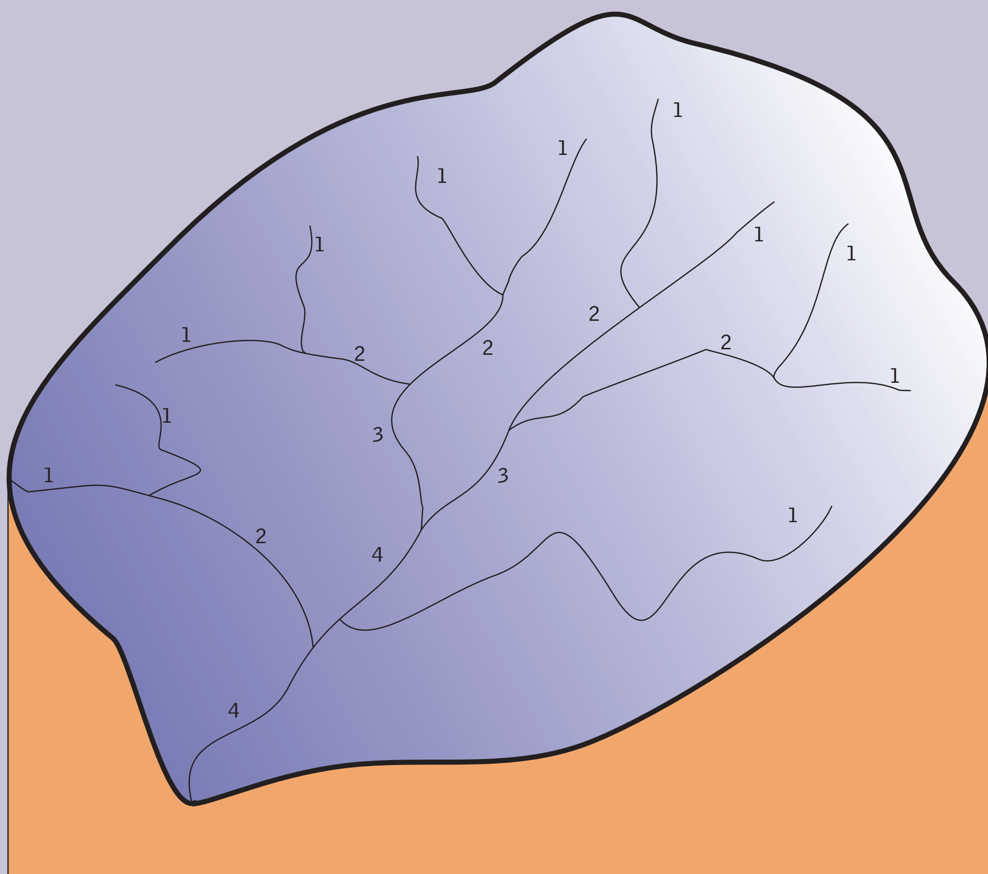
Screenshot of interface of Google Earth Pro

Source: Google Earth Pro software

HOW TO DETERMINE THE ORDER OF STREAM

Stream order is the branching level of any drainage network system. Typically, the lower the order, the smaller is the stream, and lesser is the runoff through it. When a stream of one order meets another of the same order, the two stream form a stream of the next order. For example, if two streams of the second order meet, they form another stream or of the third order, which is not possible in any other case. If a lower order stream meets a higher order stream, the latter will continue its order till it meets a stream of its order (see *Figure 23: Drainage network showing stream orders*).

Figure 10: Drainage network showing stream orders



Source: Compiled by CSE

Types of GIS maps required to locate groundwater recharge zones

To identify potential recharge zones or points in any watershed or village, specific maps are required. These maps are analysed using GIS softwares. Some of the important maps required are described in the following sections.

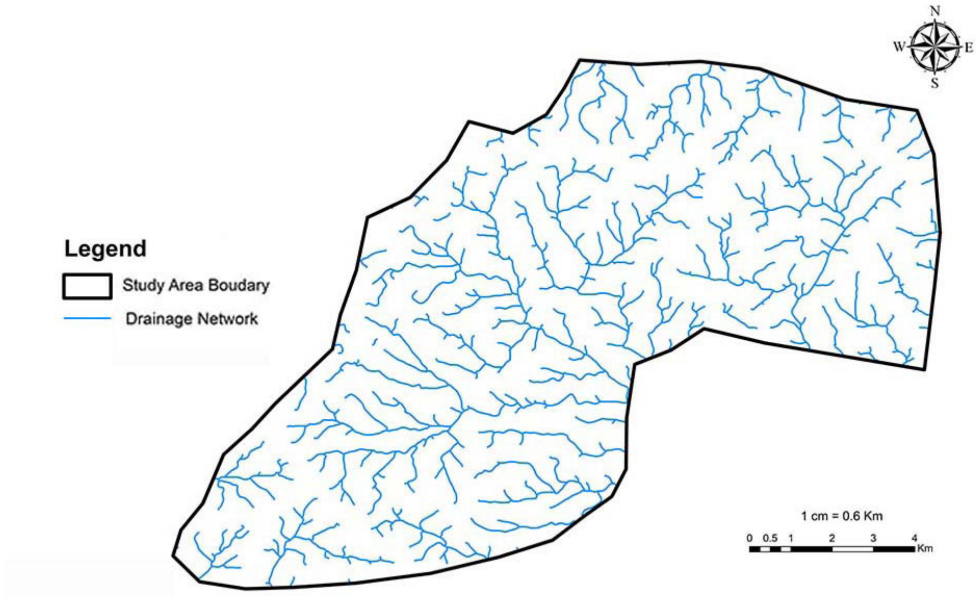
a. **Drainage map:** A drainage map shows all the streams, rivulets, rivers and their tributaries in a specific watershed. The drainage pattern shows the flow of all streams/rivulets etc. The streams can be of any order (i.e. level of branching; lower orders indicate lower levels of branching. Brancing is always defined by a whole number, e.g. first order, second order etc.)—from first order at the ridge to a higher order near the end of the watershed. The terrain and slope of the watershed influences the drainage network. The more undulating the terrain, the higher the drainage density. In QGIS, a drainage network can be generated using Digital Elevation Model or DEM, which contains the elevation data of the terrain. A set of processes (spatial analysis) will generate the drainage pattern of any selected watershed.

   The process of generating the drainage pattern in QGIS is as follows:
   i. Download DEM from Bhuvan or USGS.
   ii. Import the DEM file (raster) in QGIS.
   iii. Use "Warp Projections" to reproject the DEM in a new Coordinate Reference System (CRS).
   iv. Fill in the sinks using "Fill Sinks (Wang & Liu)".
   v. Generate drainage network using the tool "Strahler Order".

The aforementioned steps will generate the drainage network of any basin, watershed or catchment. These drainage networks can be verified by superimposing the generated drainage network with the base map of in Google Earth Pro (see *Map 2: Prototype of drainage network map*). Subsequent maps have been created based on the data from Bundelkhand region.

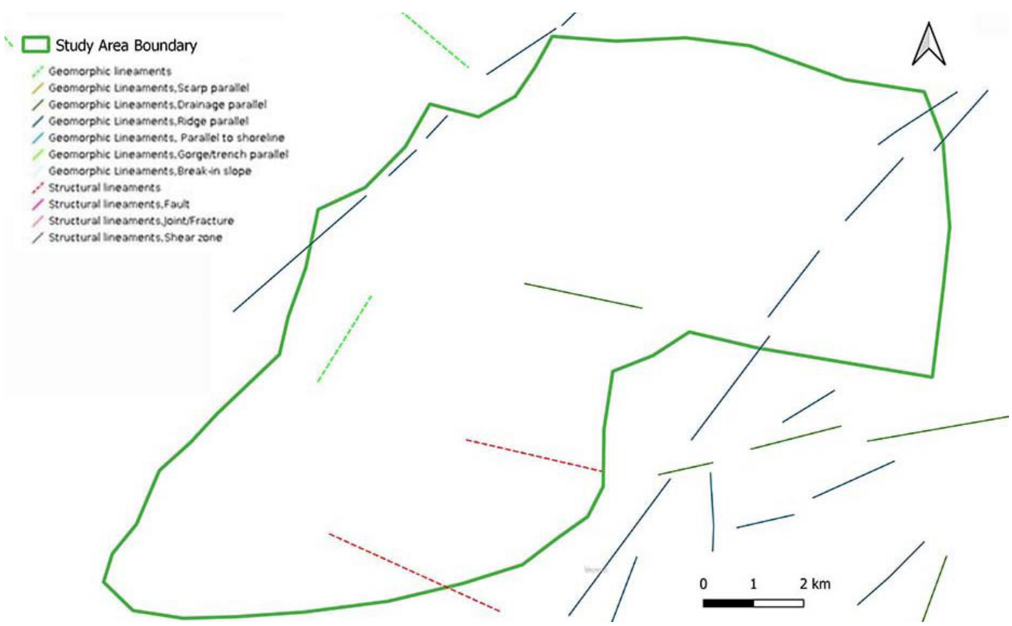
Lineament map: A lineament is an underground formation such as a fracture, fold or fault in the geological structures of an area. A lineament map indicates a zone in a watershed or village where there is a possibility of groundwater recharge or discharge. A lineament map of any part of India can be obtained in the form of Web Map Services (WMS) layers from the Bhuvan portal. The layers can be imported in QGIS for further analysis (see *Map 3: Prototype of lineament map*).

Map 2: Prototype of drainage network map



Source: Compiled by CSE

Map 3: Prototype of lineament map

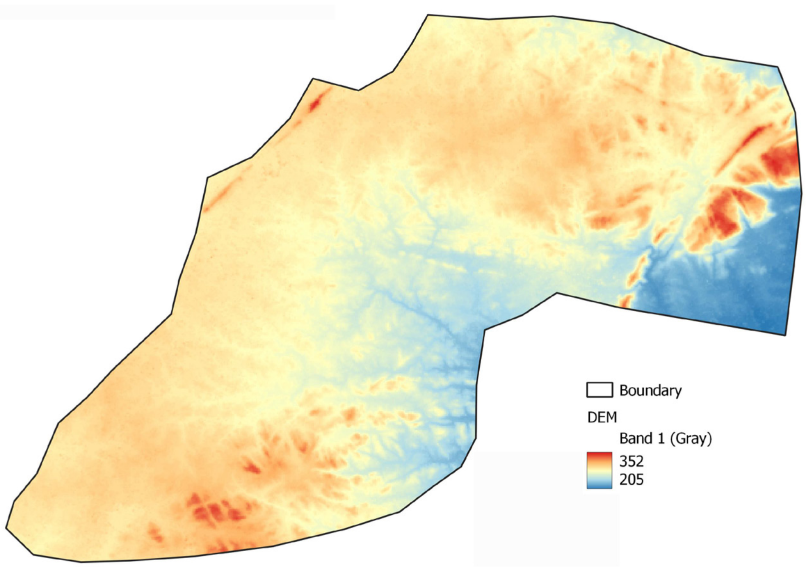


Source: Compiled by CSE

Digital elevation model (DEM): A DEM is a raster file, which contains elevation data in the form of a grid with elevation values. The grids can be of smaller or larger sizes, depending upon the resolution of the sensor capturing the elevation data. A higher resolution DEM will give better analysis and help in accurate analysis of the selected area. The DEMs are used to create an elevation profile of the watershed and to generate the drainage pattern. The different colours in the maps show ridges, mountains, depressions and valleys (see *Map 4: Prototype of digital elevation model [DEM]*). The DEMs obtained from the Bhuvan portal have a grid of 30 m x 30 m resolution. Higher resolution DEMs can be purchased from authorities like the National Remote Sensing Centre (NRSC).

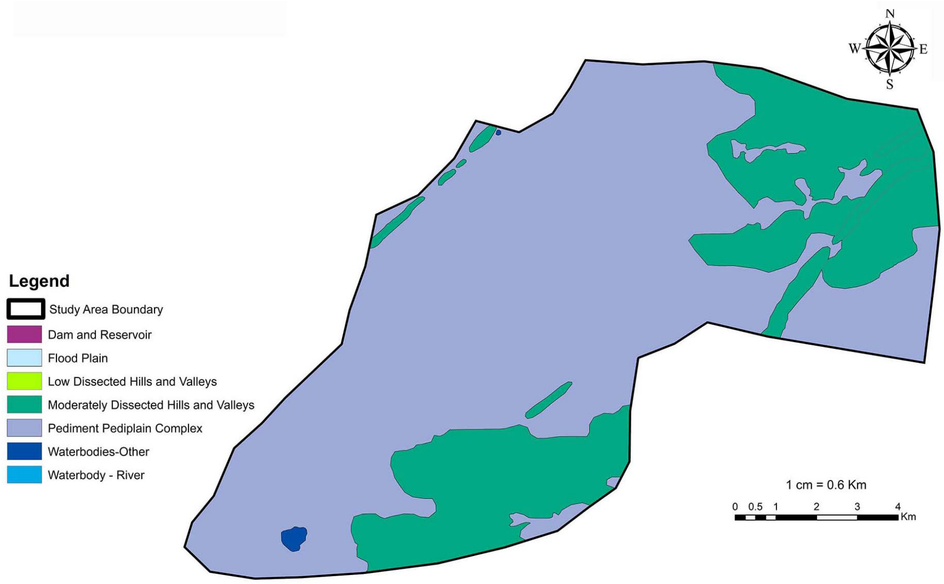
Geomorphology map: A geomorphology map contains information about the physiography of a watershed. The map holds information about the kind of natural processes the geography of an area has undergone in a historic timespan. The geomorphology map of any Indian state, district, block or village can be obtained for free from the Bhuvan portal. A watershed can have different geomorphological

Map 4: Prototype of digital elevation model (DEM)



Source: Compiled by CSE

Map 5: Prototype of geomorphology map



Source: Compiled by CSE

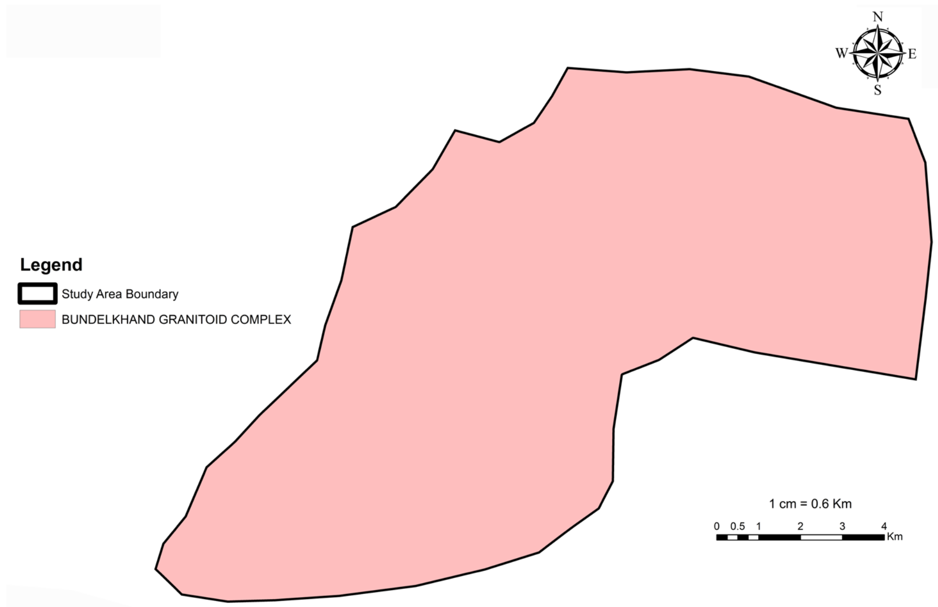
formations like pediment, pediplain, denudations, dissected hills, settled sand dunes etc. (see *Map 5: Prototype of geomorphology map*).

Geology/lithology map: A geological map shows the information of the rock types in a watershed. Different types of rocks are mapped and shown in a geological map. To plan a groundwater recharge or water harvesting system, it is important to understand the geology of any area of interest. There are certain rocks (e.g. quartzite, shale etc.) which do not allow groundwater recharge, and in these cases, harvested rainwater can be stored in artificial storage structures. Areas of sandstones are favourable for groundwater augmentation.

When a geological map is superimposed with the lineament map, it gives a more precise location for groundwater recharge structures (see *Map 6: Prototype of a geological map*).

Land use land cover map (LULC): A LULC map is a representation of type of land use in any area of interest. There are various categories of land use such as agriculture, forest, barren, wasteland, habitations etc. To locate any recharge structure, it is important to understand the land use types of an entire watershed.

Map 6: Prototype of a geological map



Source: Compiled by CSE

For example, agricultural land cannot be used for groundwater recharge. In agricultural lands, only farm ponds can be constructed.

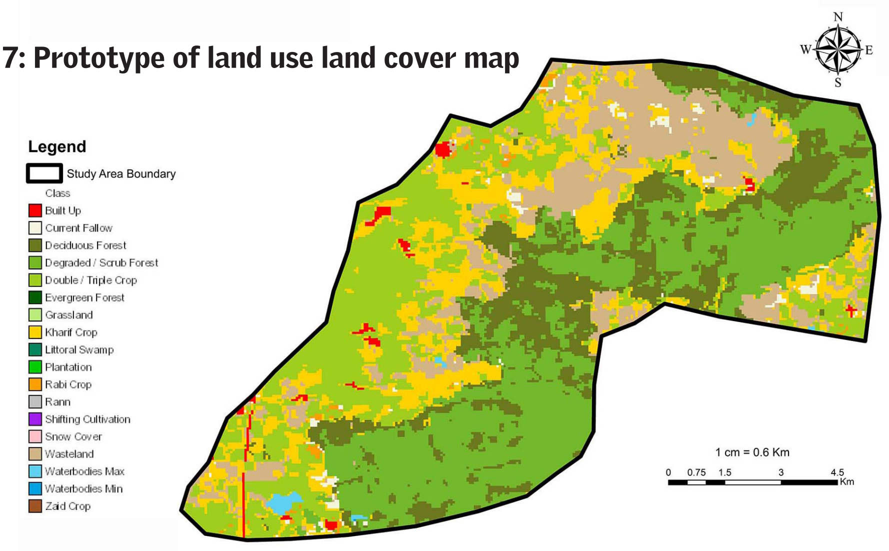
An elevation map superimposed on LULC will give an idea of forest cover and its locations in the watershed. A typical LULC map is shown in Map 7, which shows all kinds of land use in the selected boundary.

b. **Soil map:** A soil map depicts different types of soil present in a watershed. The knowledge of soil type in a watershed helps in understanding the type of groundwater recharge structures suitable in different types of soil. The superimposition of a soil map on a geology/lithology and geomorphology makes the decision on the type and location of groundwater recharge structures more precise (see *Map 8: Prototype of a soil map*).

Superimposition of thematic maps

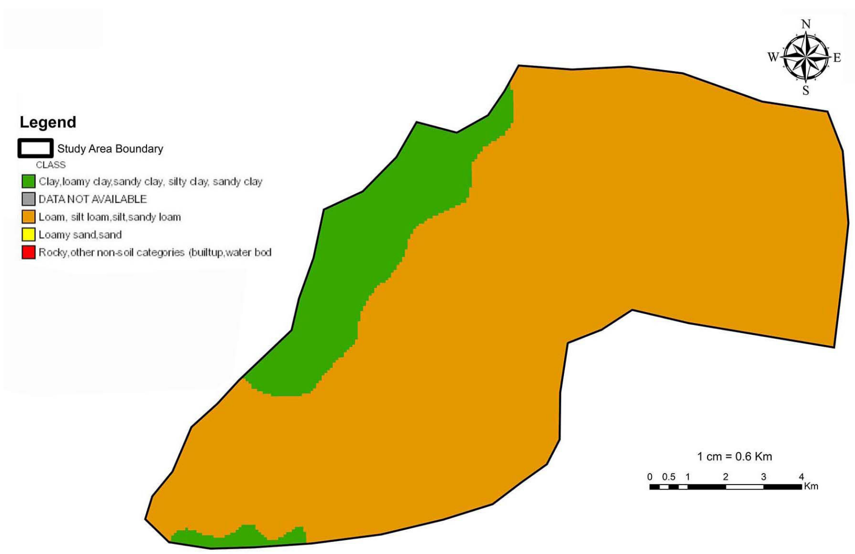
The generation of thematic maps through GIS softwares is not enough to understand the location of groundwater recharge structures. Superimposition of generated thematic maps is important to identify potential groundwater recharge zones.

Map 7: Prototype of land use land cover map



Source: Compiled by CSE

Map 8: Prototype of soil map



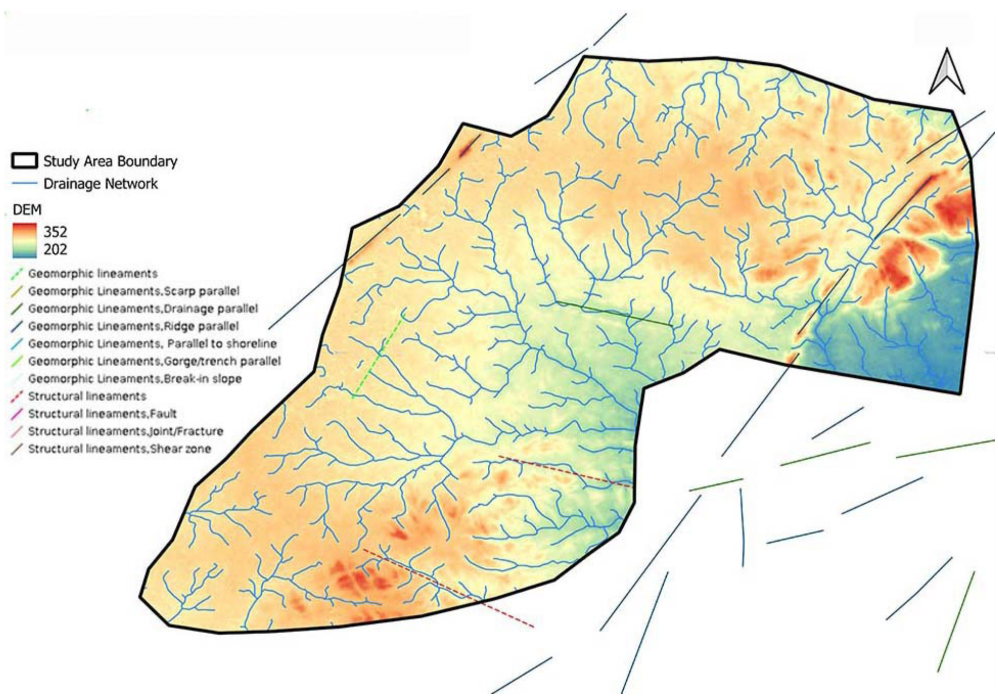
Source: Compiled by CSE

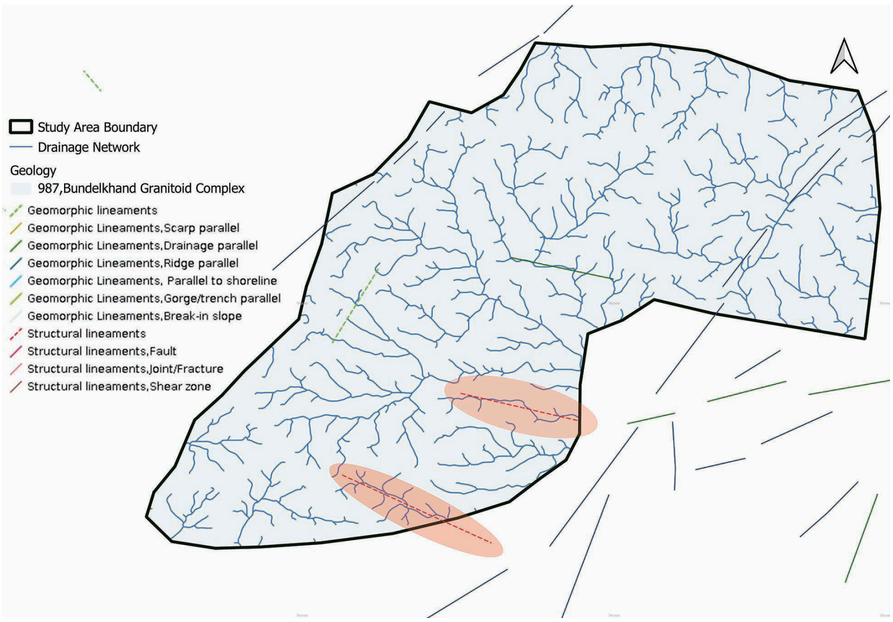
For superimposition of the layers, there are two types of processes. The first process is an automatic method, known as Analytical Hierarchy Process (AHP), where different thematic layers are superimposed, and each layer is given a specific weightage (defined by percentage). In this process, software runs a programme on weightages of layers and generates the recharge and discharge areas in a watershed. This method requires an in-depth knowledge of GIS tools to operate. The second method is non-automatic and every layer is dealt separately by the user. So, a basic understanding of GIS is required for this method. For example, superimposition of geology, lineament and drainage maps will give an idea of the streams flowing through any lineament or rock type (see *Map 9: Prototype of composite maps*).

The following set of compositions can be developed by superimposing maps for better analysis:

a. **Geological, lineament and drainage map**
b. **Elevation, lineament and drainage map**
c. **Geomorphology, lineament and drainage map**
d. **LULC, drainage, elevation and lineament map**
e. **Groundwater prospects, lineament and drainage map**

Map 9: Prototype of composite maps



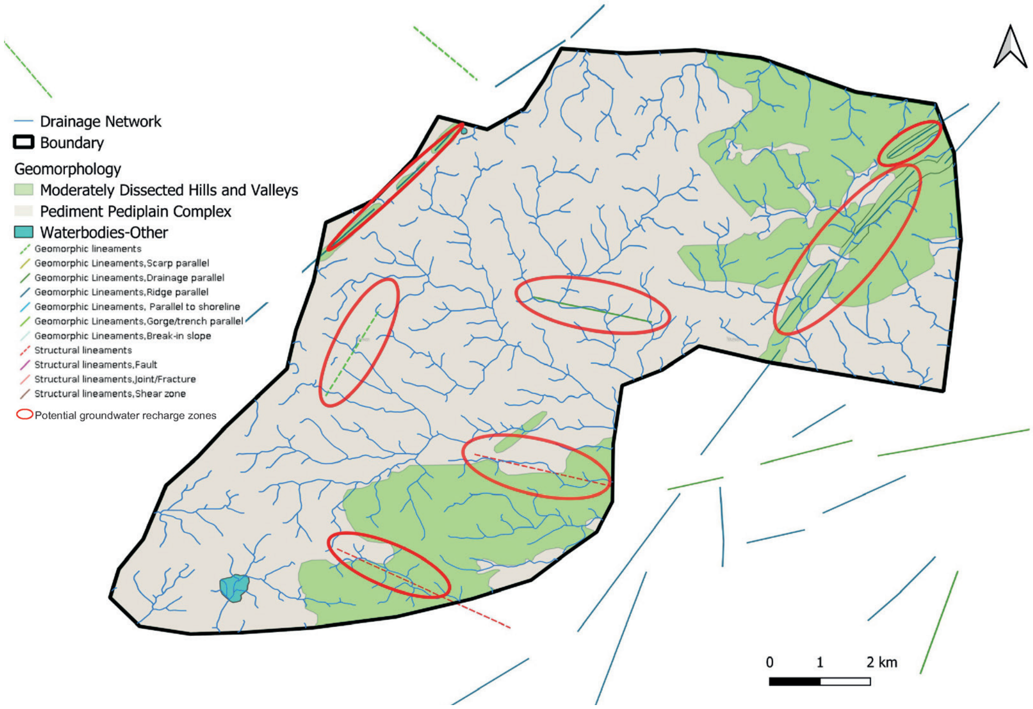


Source: Compiled by CSE

A geological map represents the presence of type of rocks in the watershed while a lineament map represents the presence of folds, faults or fractures. The superimposition of drainage maps with these two layers will help to identify suitable locations where the stream flows along or across the lineament in a certain type of geology. For example, in Map 9, drainage, geological and DEM maps are superimposed on one another. As can be seen from the shaded ellipse, faults are present along the drainage lines towards the downstream side. The elevation map superimposed on the drainage and lineament maps confirms the gradient of the watershed.

To analyse the map, the locations where faults are aligned with the streams can be chosen for groundwater recharge in the watershed. Steep slopes in a watershed means that loose boulder check dams, brushwood check dams etc. can be constructed. The detailed design criteria and calculations of these structures have been discussed in Chapter 5. For example, in Map 9, faults and aligned streams are at the lowest slope, so a check dam or percolation tank will be suitable groundwater recharge structures. The final decision should be taken only after physical verification of the location. But a draft planning can be made about the type of groundwater recharge structures based on the superimposition of different thematic maps.

Map 10: Activity planning map



Source: Compiled by CSE

In Map 9, a massive impermeable area—which should be avoided for groundwater recharge—can be mapped. In these areas, the only option to supplement the water supply is through storing harvested rainwater in artificial tanks.

For the sustainability of groundwater sources and to ensure water security, the planning of groundwater recharge should be done from the ridge to the valley in any watershed. The watershed principles follow the concept of reducing the velocity of surface runoff from the higher elevations of the watershed, preventing soil erosion. Groundwater recharge structures are designed based on slopes, stream orders and area of the catchment.

For irrigating crops in drought-prone areas such as western Rajasthan, Bundelkhand area (parts of Madhya Pradesh and Uttar Pradesh) and the rain-shadow area of Maharashtra, farm ponds are the best option. Farm ponds should be constructed downslope of a farm so that surface runoff can collect in it.

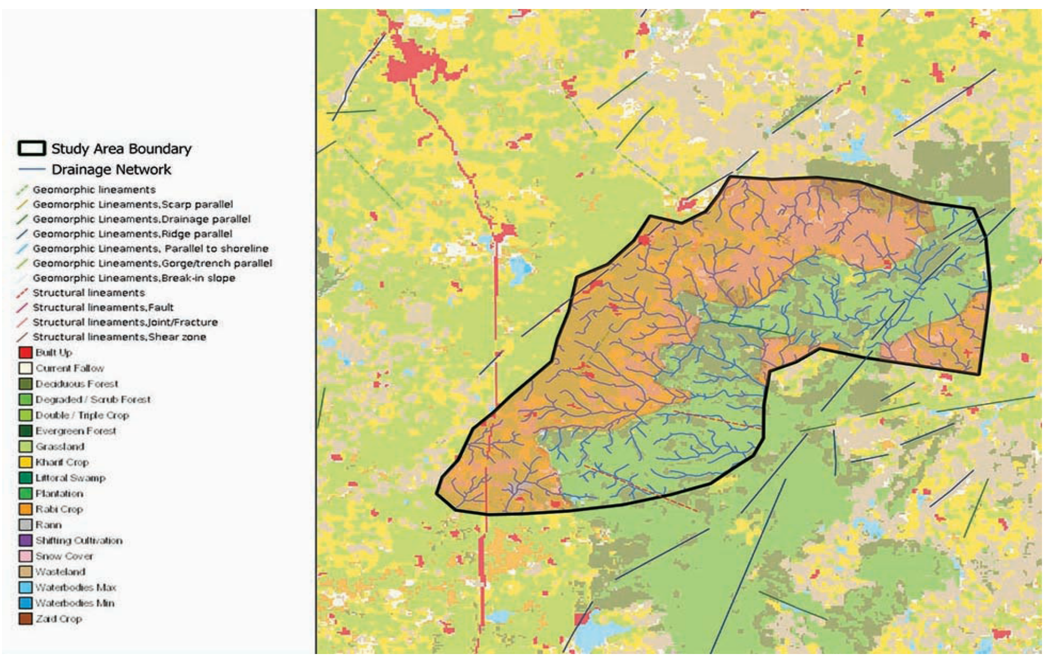
Crops such as paddy which require stagnant water for at least 15–20 days need farm ponds constructed near these fields so that water is readily supplied even during dry spells.

To prevent soil erosion at higher elevations, reduce runoff velocity and facilitate initial groundwater recharge, specific structures are planned in drainages of lower orders at higher elevations (i.e. with slope 15–25 per cent). Examples of such structures include loose boulder check dams, brushwood check dams, small gabions, gully plugs etc. These structures have small catchments in the range of 2–50 hectare.

Superimposition of the drainage map on LULC will help in locating the aforementioned structures in small-order drainages emerging from forestland or ridge areas. The drainages and surface runoff in croplands can be tapped by constructing a farm pond for irrigation (see *Map 11: Composite map [drainage, LULC and lineament]*).

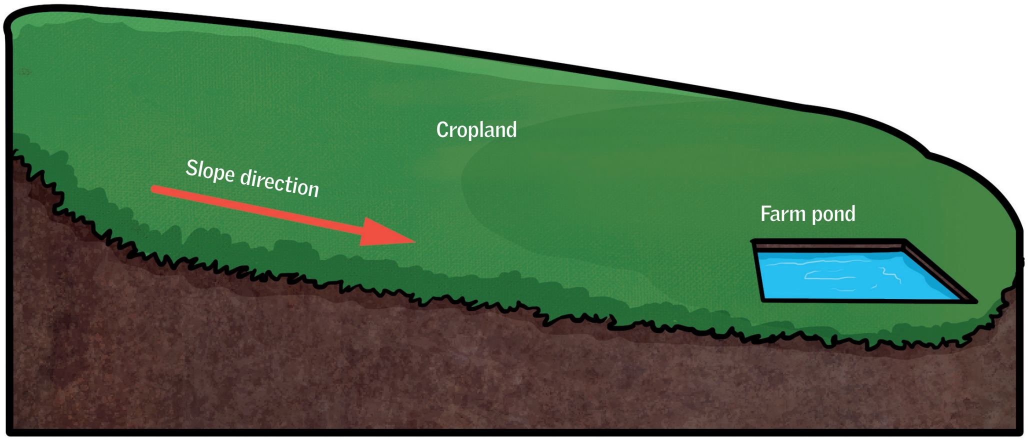
The red-shaded area in Map 11 falls largely under cropland and is suitable for selection of farm ponds. The feasibility of construction can be studied during a site visit, but initial planning can be done through the LULC and drainage composite map. The soil map can also be integrated with this composite map to analyse the type of soil at the selected site for farm pond. If the soil is of the loose type, such as sandy or loamy soil, a thick lining of clay soil must be applied at the base of the farm pond to prevent percolation from farm pond.

Map 11: Composite map (drainage, LULC and lineament)



Source: Compiled by CSE

Figure 11: Illustration of a farm pond



Source: Compiled by CSE

Calculation of catchment for a structure

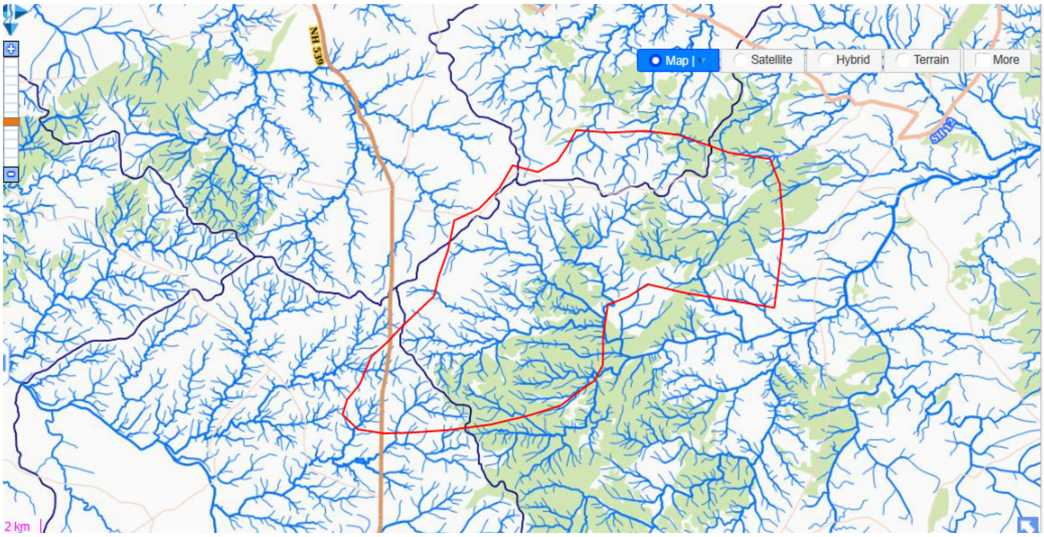
A calculation of the area of catchment is necessary for effective and efficient design of any groundwater recharge structure. The area of catchment and its LULC determine the amount of runoff generated at any selected site/point (this can be done manually or digitally). The process of calculation of area of catchment can be done manually or digitally.

a. Manually: Using toposheet, tracing paper and graph
b. Digitally: Using GIS tools

The manual method involves the use of a toposheet of any available scale (generally used ones are of the scale of 1:50000 or 1:25000). The selected point is marked in the toposheet, by identifying it through landmarks followed by tracing the drainage network on a transparent graph paper or tracing paper. The scale of toposheet is important in calculation of catchment area. For example, in a toposheet of scale 1:50,000, 1 centimetre on a graph will indicate 50,000 centimetre (500 metre or 0.5 kilometre) on the ground. Hence, one big square of graph paper of 1 square centimetre will represent 250,000 square metre or 25 hectare on ground. This conventional manual method has been used widely for small as well as big structures, including big irrigation dams. But the process becomes much easier with the use of modern technologies like GIS. For example, the Bhuvan web portal (www.bhuvan.nrsc.gov.in) can be used to delineate the catchment of any watershed or groundwater recharge structure (see *Figure 12: Illustration of a catchment*).

The point in red in Figure 14 shows the selected site for which a catchment has to be

Figure 12: Illustration of a catchment



Source: Compiled from www.bhuvan.nrsc.gov.in as viewed on January 10, 2023.

drawn. It is the site where a groundwater recharge structure must be constructed, and so its catchment area is calculated to estimate the amount of runoff generated. To do this, the "tools" option in the Bhuvan web portal contains the "draw tool" option, which is used to draw the catchment. Selecting the option would activate a tool panel from which a colour of the catchment line and a polygon tool must be selected. The boundary of the catchment is drawn. by tracing the starting point of all the first order streams, which contribute to the higher order stream on which the groundwater recharge structure is selected.

This boundary of the catchment is then exported as a layer to the software, Google Earth Pro, where the catchment area can be found by right clicking mouse on the exported layer (see *Figure 14: Illustration of creating catchment in Google Earth Pro*).

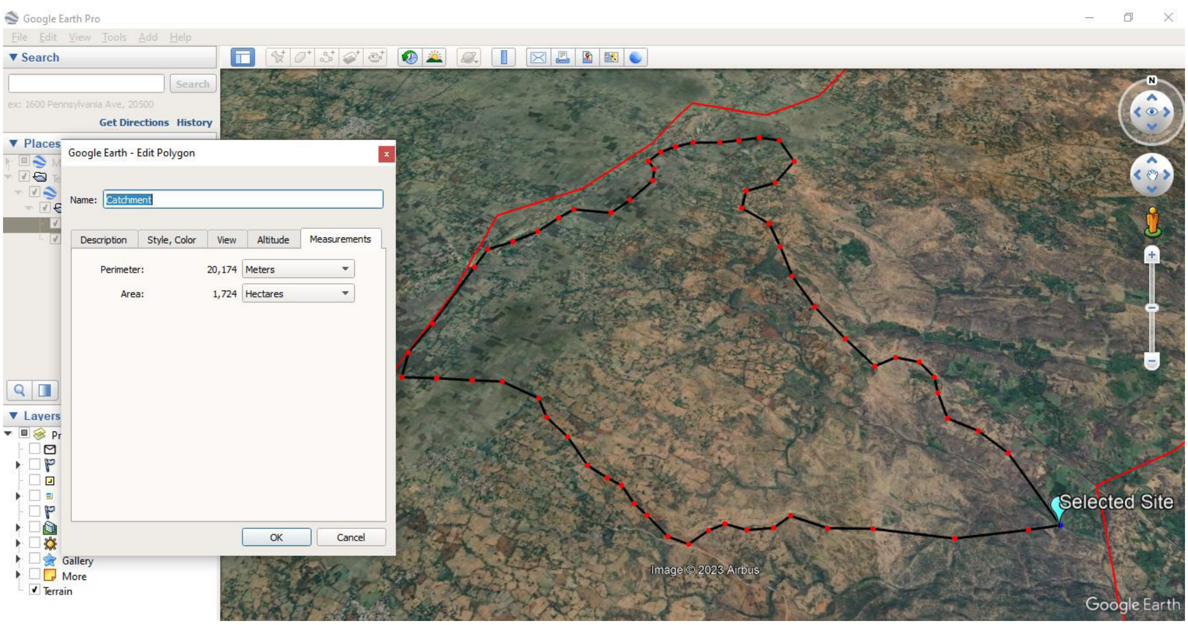
This method of calculation of catchment area is simple and quick to follow. The calculated area of the catchment can be used in further hydrologic and hydraulic design of structures for groundwater recharge and rainwater harvesting (see *Figure 13: Illustration of creating catchment in Google Earth Pro*).

Geospatial technology is a powerful tool, useful in planning of water-related activities, especially rainwater harvesting and groundwater recharge. Mapping existing groundwater recharge structures, land cover and waterbodies help in analysing various data and facilitates better planning of groundwater recharge

Figure 13: Illustration of selected site and its catchment

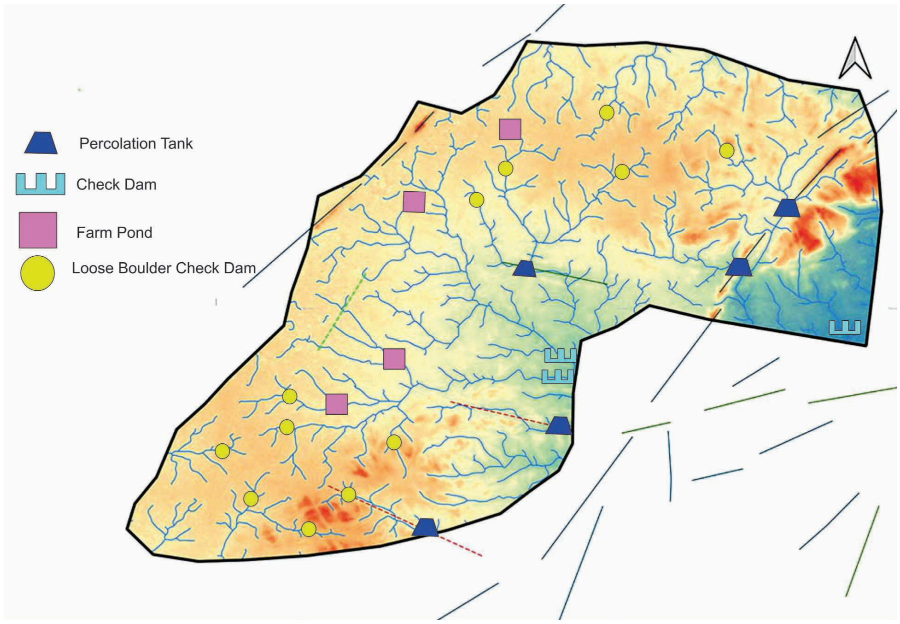
Source: Compiled from www.bhuvan.nrsc.gov.in as viewed on January 10, 2023.

Figure 14: Illustration of creating a catchment in Google Earth Pro



Source: Data analysis in Google Earth Pro software

Map 12: Activity planning map



Source: Compiled by CSE

structures. A final composite map is prepared, with all the groundwater recharge structures planned at different locations illustrated—these can be verified during a field visit. For example, in Map 12, percolation tanks are planned for groundwater recharge at the location where the lineament and drainage network intersects. In higher elevations, where the streams of first or second order flow, loose boulders check dams across streams are the most suitable structures. In areas where there are agriculture fields, farm ponds are planned for irrigation of crops. Check dams are located at lowest elevations.

CASE STUDY

The following three case studies illustrate how community knowledge has helped in improving water security in three different states of India.

How rejuvenation of traditional waterbodies has increased water security in Bundelkhand region

Issues

Chandeli tanks ((big ponds constructed by Chandela dynasty kings), in the region of Bundelkhand, are one of the most important structures constructed to provide water security to inhabitants of the region. The Chandela dynasty had a vision to secure their region with water for a prosperous society.

Constructed between ninth and thirteenth centuries, these tanks served the region well until they started to lose their storage capacity due to high siltation, broken bunds and other problems arising from non-maintenance. These traditional waterbodies served people and animals for centuries. Many of them have now disappeared due to encroachments for habitations and agriculture.

Several grassroots organizations joined hands with the government for rejuvenation of these important structures. Chandeli tanks are the source of large volumes of water, and strong action plans were made to revive them.

A Chandeli tank in Khajaraha Khurd village, Jhansi district, has a surface area of around 5 hectare and a potential command area of 10–15 hectare. The pond suffered from desiltation, broken bunds and a broken outlet. This reduced the water storage capacity of the pond, and it was of little use. Jhansi-based grassroots organization Parmarth Samaj Sevi Sansthan undertook rejuvenation of pond.

Solutions and impact

To rejuvenate the pond and increase productivity, a women's community institution—called Jal Saheli (literally, friend of water)—was set up comprising eight to 10 members. The Jal Sahelis initiated the work of mobilizing people and motivated them for the work. They sensitized and convinced the community to work as labour as a contribution towards the rejuvenation of pond. The team from Parmarth carried out the technical studies, including site visits, engineering surveys, detailed designing for capacity calculations and other studies. The work was carried out under the programme "Securing Water and Land Rights for Marginalized Communities through People's Advocacy".

The pond was desiltated in the initial phase to increase the water storage capacity. The embankments and waste weir were repaired, and the work yielded good outcomes.

The community is happy with the effort it made as it had fruitful results. The pond rejuvenation resulted in around 20–30 acre of land being brought under irrigation. Previously, farmers near this pond cultivated only one crop. But this work has helped farmers cultivate rabi crops as well, providing increased incomes. The farmers now cultivate wheat, peas, mustard and chickpea. Water is now available in the pond in increased quantities and stays in the pond for longer periods.

Apart from the increase in irrigated area, the pond rejuvenation work has also increased the water levels in wells. According to community members, the water level in the wells downstream has increased to 5 feet. The more the accumulation of water in the pond, the more is the amount of recharge. Due to increase in the water level of wells, farmers are cultivating more fruits and vegetables and enabling their families to have more nutitious food.

PHOTO CREDIT: PRADEEP KUMAR MISHRA, CSE

Members of a water-user group in Khajaraha Khurd village, Jhansi district

"This pond is an age-old traditional water structure that has served us for centuries. Due to damage to bunds and outlets, water could not be retained for long periods. But after it was repaired and renovated, the situation has changed. The wells have increased water levels and we can irrigate our fields from this pond."

Balvir Singh Rajput, 43, resident of Khajaraha village, Jhansi district

CASE STUDY

Community-driven water management systems for source sustainability of water resources

> "Farmers are benefiting well from the Cement Nala Bund. Before 2012, we had to construct tube wells of 500–600 feet to draw water. In summers the situation worsened as even most of the deeper wells went dry or had intermittent yield. Farmers were dependent on monocropping for their livelihoods (when the crops were rainfed)."
>
> —Ashokbhai N. Parmar, resident of Mota Munjiyasir village, Bagatsara tehsil, Amreli district

Rajkot and Amreli districts, in Gujarat, are semi-arid climatic regions. The average annual rainfall of Rajkot and Amreli districts is 700 mm and 736 mm respectively (1988–2022). In spite of receiving rainfall in the higher ranges, water availability is a challenge as most of the rainfall is lost as surface run-off and low percolation.

Mota Munjiyasir village in Amreli district has the complex hydrogeological setup. It largely comprises hard rock that has poor permeability. The natural percolation of water is low, and most of the rainfall is lost as surface run-off due to lack of water harvesting and recharge infrastructure. After 2001, shallow aquifer zones (groundwater-bearing formations) became dry and almost every dug well—which was approximately 40–60-feet deep—dried up and was abandoned. The community started exploring deeper aquifer zones to meet their domestic, drinking and agricultural needs. With growing population and increased demand of water the situation was exacerbated, and the water level started declining over the years.

The existing Cement Nala Bund previously catered to the irrigation requirement of farmers, but has been in a dilapidated condition since 2012. The community and farmers decided to rejuvenate it by first desilting and creating a proper embankment for the drain on which the bund was constructed. It was then renovated on the basis of an earlier design and specification in 2018. The Cement Nala Bund has helped to hold the run-off of rainfall—which was earlier lost in the village—and harvested water slowly percolates to the subsurface zone, augmenting groundwater and increasing soil moisture of the surrounding areas.

This has benefitted farmers immensely as water availability and water levels in the wellshave increased. Soil moisture in nearby lands has also improved and irrigation required is also less, saving both water and electricity.

"Now, after the construction of the Cement Nala Bund in 2018, wells up to the depth of 250–300 feet are sufficient for our needs. The water levels in the wells have risen by 60–80 feet in the last two to three years. Earlier we would cultivate only cotton and groundnut; now we are able to grow as much as we want of crops such as wheat, garlic, black gram and soya bean in addition to cotton and groundnut."

—Prakash, resident of Mota Munjiyasir village, Bagatsara tehsil, Amreli district

"Earlier we used heavy capacity pumps for extracting water from tube wells which cost us a lot in electricity charges. Now since the water levels have improved and fields are irrigated fewer times due to improved soil moisture, we can use low-capacity pumps and save on electricity charges. We save 60–70 per cent of the money paid for electricity. Also, the income per acre of land has doubled from Rs 20,000–25,000 per acre to Rs 45,000–60,000 per acre depending upon the crop types. The extra income we generate from agriculture has been used for buying tractors and cattle, and using good-quality seeds and fertilizers for higher outcome."

—Janti Bhai, resident of Mota Munjiyasir village

A seasonal stream, starting from Jasdan district, passes through Mota Munjiyasir village and finally merges in Bhadar Nadi in Porbandar district. Before 2003 the stream flowed only for two to three months during the monsoons. The water, instead of holding in the village, was lost as run-off. In 2003, seven check dams were constructed on this stream on a 10-km stretch covering eight to 10 villages.

All the water-conservation structures in these villages have been financially supported by the Shroff Foundation Trust and other organizations. But the community took the ownership right from planning and implementation to operation and maintenance. All the structures in the villages were constructed by shramdaan (voluntary service involving labour or physical effort offered by the community). Step-by-step monitoring was also done by the community.

"Pransla village in Rajkot district was also grappling with falling water levels and increased salinity in groundwater. Most of the irrigation depended on rainfall. Eighty per cent of the dug (shallow) wells were abandoned and the depth of tube wells increased from 200–250 feet to 400–450 feet."

—Sukabhai Mudubhai, resident of Pransla village, Upleta tehsil, Rajkot district

"Before 2002, the community constructed wells of 400–500 feet to withdraw groundwater. But after construction of the check dams, the water level has risen as a result the recharge of sub-surface zones and wells of 200–250 feet suffice for the community. The dug (shallow) wells, which went dry after 2000, have been rejuvenated as percolated rainwater harvested through check dams recharged the groundwater systems."

—Bhupat Bhai, resident of Pransla village, Rajkot district

"The quality of water has improved. In the last four or five years there has been no report of groundwater salinity, which used to be high (in the range of 1,500–1,800 ppm in 2012, now it is 900–1,000 ppm in 2018 as per the test by gram panchayat). This scheme benefits farmers from at least from eight villages. The productivity of the farmers per acre for cotton was was 15–20 mann per acre (1 mann = 20 kilogram); now it has increased up to 35–40 mann per acre of land. Similarly, production has also increased for crops also such as wheat, black gram and vegetables."

—Sukhabhai Mudubhai, resident of Pransla village, Rajkot district

Approximately 200 households live in Pransla village. Family members of seven households contributed shramdaan every day continuously for six months. The beneficiary groups who are directly impacted by these interventions, especially farmers whose land is near to these interventions, ensure the sustainability of the structures. All the structures in this village are very well maintained—some have been functional since 2003 but are still in good condition. No structures were found to be in abandoned or dysfunctional.

By increasing cultivable land with improved-moisture holding capacity and improved groundwater levels, the community-driven water-conservation and harvesting initiatives have improved the conditions for agriculture and led to increase in crop intensity. Improved land and water resources has improved the livelihood of the people in the villages.

PHOTO CREDIT: FARAZ AHMAD

The Cement Nala Bund constructed by the community in Mota Munjiyasir village in Bagatsara tehsil, Amreli district

PHOTO CREDIT: FARAZ AHMAD

Check dam constructed on a stream passing through Pransla village in Upleta tehsil, Rajkot district

CASE STUDY

Revival of existing waterbodies has solved water problem in Barmer district, Rajasthan

Background

Molap Talab, also known as Nar Har, is a surface water source, around 750 years old, in Tarsingri Sodha village of Barmer district, Rajasthan. It was the only source of water for more than 50 villages for all their water requirements. Communities such as the Langas and Manganiars are completely dependent on it.

In recent decades, the source has deteriorated due to extensive use the water for agricultural needs, dumping of waste and encroachment. One of the major reasons for this was that there were no community involvement. There was also negligence by government departments.

The depletion of the water source caused the villagers great stress. According to Tikamsingh Rajpurohit, a resident of the village, due to unavailability of water there was a large-scale migration of families to nearby states such as Gujarat and Maharashtra in the early 2000s. There is no any alternative source of water within a radius of 10 km of the village. For their water needs, the villagers used to order water tankers from private companies, which cost around Rs 3,000–3,500 per visit for 5,000 litre of water and lasted around 15 days for a family of five members. A family needs to order water from a tanker twice in a month to cover all of their water needs. This costs around Rs 6,000–7,000 and leaves a huge dent on the family income. Apart from agriculture, there is no alternative source of income for the villagers of Tarsingri Sodha, and for their water requirements for agriculture they were largely dependent on rainfall. All this meant low income and large-scale migration etc.

Because of extreme weather events like heatwaves and high intensity and low duration rainfall, Rajasthan has always been exposed to water-stress situations, and water security is an issue for the population of the state. Extreme climatic conditions affect the water sustainability of waterbodies such as ponds and lakes as they dry up, leading to overexploitation of groundwater to meet demand. The groundwater level in Barmer district is very low, at around 36.13 metre below ground level (mbgl). The Groundwater Assessment Report 2013 prepared by the Central Ground Water Board declared Barmer an “overexploited” region. Further, alarmingly, the report said that while the district groundwater recharge rate was

278.01 million m^3, the consumption rate was 312.14 million m^3. The groundwater level in the district has been declining at the rate of 5–6 metre each decade. Major parts of the district are covered by hard-rock formations such as Malani rhyolite, Jalore granite and Siwana granite of Post Delhi (the geological structure formed after the Delhi Supergroup of rocks), which have poor water-yielding capacity. These areas also suffer from poor water quality. In some areas, the groundwater is also highly saline. As villages located in these areas depend solely on groundwater for their drinking-water needs, the situation becomes critical in summers and in drought years.[2]

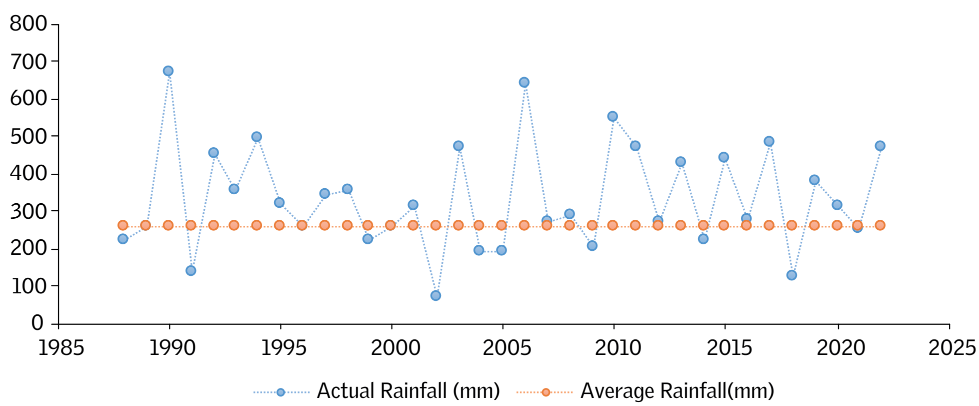
"Groundwater in the village is mostly available at 400–500 feet. Also, it's mostly saline. Previously, people were not able to get pure and adequate water for drinking and irrigation. Surface water is the only source of drinking and irrigation purpose in the village. The groundwater was very deep and it was uneconomical to pump it for domestic use. It was also contaminated. Thus people could not get adequate water for drinking and irrigation. But now, after revival of the Molap Pond, people depend on the surface water source created."

—Vivekanand Vidyarthi, Junior Engineer, Watershed and Soil Conservation Department

Plan

Tirsingri Sodha village was, in spite of the issues, able to conserve surface water. The village is an arid region, with 334 mm of actual annual rainfall (see *Graph 5: Actual rainfall in Barmer district [1988–2022]*). Despite this, 370 households protected their village from water scarcity and made it self-sustainable by protecting and regularly maintaining the surface water source, 2 km from the village.

Graph 5: Actual rainfall of Barmer district (1988–2022)



Source: https://indiawris.gov.in/wris/#/rainfall

To find a solution to the problem of water scarcity, the village created a watershed committee in 2010, but it was not functional until 2015. In 2016, the state government launched a scheme—Mukhyamantri Jal Swavlamban Abhiyan—to conserve water and harvest water across the state. The main objective was to meet the minimum requirement of water in rural areas to address problems arising from lack of water during times of famine. Once the villagers learnt about the scheme, they recreated the committee with 11 members to approach the Watershed Department of the state government for rejuvenation of the water source. Rejuvenation of the source was initiated in February 2016 and completed in December 2016.

Operation and maintenance

"For regular operation and maintenance of the source, the committee collects Rs 1,000 from each household every year. The committee has a separate bank account for deposit of the collected money, which is used for desilting and deepening the water source. The committee also appoints a security guard in summers for regular monitoring, and pays him a salary of Rs 12,000 per month. If a tanker takes water from the source in summers, the committee charges around Rs 100 per visit. In 2021, the total collection of the committee for operation and maintenance was around Rs 12 lakh."

—Tikam Singh Rajpurohit, 48, committee member, Thob village, Barmer district

Impact

Rejuvenation of Molap Talab has brought a major change in the village and nearby areas. Currently around 20 villages use the source for the purpose of drinking water. The water of the talab is clear, and can be drunk directly from the pond as bathing, swimming and other activities that contaminate water are prohibited. If there is a violation, the Village Watershed Committee takes strict action against the offender.

In 2022, the village received good rainfall and the pond filled to capacity. Once the pond is filled, the water is enough for three years. It also hosts thousands of demoiselle cranes, called kurja locally, especially during the winter.

After rejuvenation of the pond, migration stopped from the village and nearby areas. The talab water is also used for agricultural use.

The talab is one of the best examples of conservation of traditional water source in a desert area. With public awareness, public participation and relevant use of government schemes, the village has transformed itself from a water-scarce desert to a water-surplus and efficient one.

Specification

Molap Talab originally covered an area of 20 hectare. It has a catchment of almost 10 km and a depth of 10 metre at the centre and 2 metre at the bank. Due to encroachment, the dimensions shrunk in recent decades, but after rejuvenation the talab reverted to its natural form.

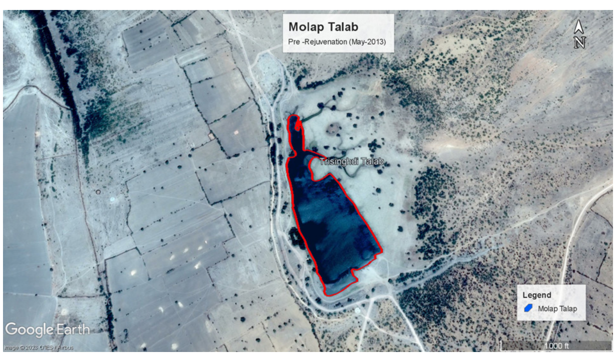
Cost

The work was done by the Panchayati Raj department in the second phase of the Mukhyamantri Jal Swavlamban Abhiyan in which the Watershed Department is the nodal agency. The total amount sanctioned was Rs 50 lakh and the final expenditure was Rs 48.46 lakh.

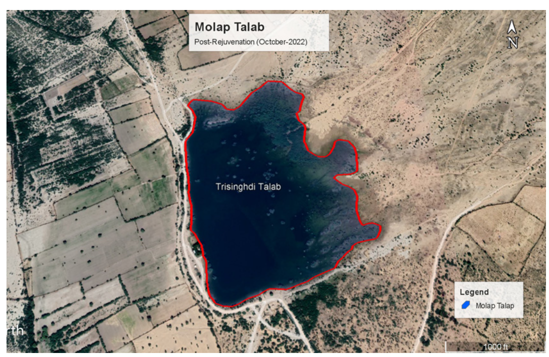
> Rejuvenation of Molap Talab brought a change in our village. We are now able to get clear drinking water and water for irrigation also. Small farmers like me can grow more crops as water is available through the year. The rejuvenation of the talab reduced dependency on tankers, which saves both time and money. Previously, my family used two tankers of water per month, which cost around Rs 6500–7500, but I can now use that money elsewhere.
>
> —Tikam Singh Rajpurohit, 48-year-old resident of Tirsingri Sodha village

Figure 15: Timeline imagery of Molap Talab

Before rejuvenation



After rejuvenation



Source: Timeline imagery analysis from Google Earth Pro

Chapter 4: Developing a decision matrix

- The type of groundwater recharge structure planned must be according to the geology and soil of that area. Sandy soil is the most suitable for groundwater recharge.
- If the area has hard massive rocks, locating lineaments/weak zones in rocks becomes important as groundwater recharge structures have to be located here.
- Different hydrogeologies need different structures for groundwater recharge.

Chapter 3 described how GIS tools can be used to decide the location of groundwater recharge structures. To some extent these tools also help decide the type of groundwater recharge structure. But the final decision is always taken after a field survey. This chapter deals with this approach.

Need for watershed approach

Various studies have been done on the historic development of watershed management programmes with regard to groundwater recharge to augment water levels. Studies on groundwater recharge processes have shown that recharge is a slow process—recharging groundwater takes a significant amount of time.[1]

Properties of rainfall, land surface and underground geology govern the process of recharge in any hydroecological region. The watershed approach has always been part of the country's water resource management. Communities have settled near rivers and other waterbodies and collected rainwater in storage tanks to utilize in lean periods since times immemorial. But extraction of groundwater started with the introduction of the concept of handpumps by UNICEF in the early 1970s and the dependence of water supply programmes on groundwater. Industries also became huge guzzlers of groundwater. Construction of deep borewells with higher rates of extraction reduced water levels in aquifers significantly and many states became water stressed during lean periods. Several districts of Maharashtra, Tamil Nadu, Haryana and Odisha were marked as overexploited districts.

Along with the inception of community development programmes, various water supply programmes have been launched to recharge groundwater. The main objectives of these programmes have been to make aquifers sustainable by recharging them through various methods.

Challenges to recharging groundwater

The process of recharge depends on the geology and geomorphology of an area. India has been blessed with diverse geography, including mountains, plateaus, coastal plains, fluvial plains and deserts. These varied geographies have different underlying geological formations that govern the extraction and recharge of groundwater. The rate of extraction and recharge is different in these different geographical regions.

Central India, including Madhya Pradesh, Chhattisgarh and part of Maharashtra, has a massive hard rock terrain that resists natural groundwater recharge. The rate of groundwater recharge in this area is lower than in areas that have a porous and permeable zone below the ground surface. Thus, identification of lineaments or fracture zones in such massive rock areas is crucial to recharging the aquifer. Without proper identification of lineaments, the structure constructed for groundwater recharge may not be possible. For example, a farm pond and a percolation tank may have the same design as both look similar. But the purpose of construction is different—one is a groundwater-recharge structure while the other is used for rainwater harvesting, with minimum or no underground seepage. In this scenario, a small mistake or negligence in identification of soil may convert the percolation tank into farm pond or vice versa.

Another challenge in recharge is that of improper treatment of catchment areas. To allow maximum water to percolate into the ground, the surface area of the catchment should be treated so that there is a reduction of velocity of runoff, and the runoff gets enough time to recharge the groundwater. If the surface runoff is not checked, the soil from the topmost part of the catchment will be eroded and silt up the ponds below.

Local communities in all these diverse geographical areas have evolved with traditional methods of conserving and recharging groundwater reserves. Since ancient times, communities have constructed various traditional water-harvesting structures to store rainwater and use it for agriculture, domestic use and livestock management (see Chapter 2).

Compatibility of recharge structure with hydrogeology

Groundwater recharge systems are unique for every hydrogeological condition. For example, a percolation tank is suitable only where the hydrogeology of the area allows percolation of harvested rainwater. It can be inferred that the area should be at a higher elevation and either have fractures in the rock or soil that is porous and permeable. In contrast, a farm pond is constructed where the geology does not allow percolation of water. Clay lining at the base of farm ponds can solve the problem of percolation of rainwater below.

Areas with high elevations and lineaments

Hills and mountains form one of the most important geographical landforms of the Indian subcontinent. Springs are the main source of water in the Himalayan states and tapped for domestic and agricultural use.

Rainfall and snowfall in upper catchments of springs percolates down through soil media and is stored in the form of groundwater, which come out as springs. Due to many climatic factors and human interventions, the yield of springs has declined. Many springs have become dry due to dwindling groundwater that fed them. In the state of Sikkim, many areas of the West and South districts have seen a decline in spring yield, and many springs have even dried up. Other Himalayan states that have springs as the only water source have also suffered a decline in the yield of springs due to changing weather patterns, declining rainfall, increasing human intervention, and increasing demand due to urbanization.

According to the report of the Department of Water Resources, Ministry of Jal Shakti, the initiative of recharging springs has been undertaken by the

Table 21: Details of spring rejuvenation work in Sikkim

S. no.	Description	Data
1.	Annual potential recharge	1,035 million litre
2.	Area treated	637 hectare
3.	Number of villages covered	20
4.	Number of springs revived	60
5.	Number of lakes rejuvenated	4

Source: Rural Devlopment Department, Government of Sikkim

Rural Development Department (RDD) of the state of Sikkim. Under the vast programme of MGNREGA, dried springs were mapped by means of technologies such as remote sensing and GIS, and all the springs that dried up were planned for revival. The upper catchments of those springs, situated in west and south, were treated by construction of staggered contour trenches (SCT), pond rejuvenation and water absorption trenches (WAT).

Due to such a vast intervention, Sikkim has been able to recharge 1,035 million litre of groundwater annually. The total area treated is accounted to 637 hectare, which covers 20 drought-prone villages. Around 60 springs and four lakes have been rejuvenated with the programme Dhara Vikas, which has proven to be a milestone towards providing water security in the state.

The hills and mountains form catchments for rivers, streams and springs. The rocks that constitute these hilly areas display lineaments in the form of fractures, faults or folds. These lineaments, especially fractures and faults, are the most suitable locations for groundwater recharge. Most of the lineaments have been mapped by the Bhuvan web portal. In such hilly formations, staggered contour trenches or continuous contour trenches are the best suitable structures for groundwater recharge.[2]

Areas with alluvial soil profile

The northern plains are blessed with rivers flowing through them. The Gangetic Plains are bestowed with an alluvial soil profile, which is good for agricultural production. Punjab has always been top in agricultural production and contributes a large share of agriculture GDP of the country.

Due to overexploitation of groundwater to boost agricultural production in Punjab, groundwater levels have declined drastically. Further, overuse of pesticides and chemical fertilizers has clogged the agricultural soil, causing waterlogging across rural parts of the state.

Groundwater recharge in such areas is a potentially difficult task. Nevertheless, efforts have been made to recharge groundwater in order to augment the water table. Out of 137 blocks of Punjab, 103 are in the overexploited category. In Haryana, 64 blocks out of 119 are identified as overexploited, while in Uttar Pradesh 290 blocks fall in this category. In Rajasthan, out of the 285 blocks, 203 fall in the overexploited category—and more will be counted if proper steps are not taken to manage the aquifer.

The recharge options in such areas comprise different activities, including watershed management for groundwater recharge. In Punjab, Haryana and Uttar Pradesh, recharge wells or recharge shafts, which penetrate alluvial formations and provide groundwater recharge, are the most suitable option. The depth of the recharge shaft depends on the thickness of the alluvium layer. States like Rajasthan and Uttar Pradesh have varied soil and geological formations. In western Rajasthan, works such as farm ponds, percolation tanks, check dams on lineaments, loose boulder check dams, gabions etc. facilitate groundwater recharge. Rooftop rainwater harvesting systems can be implemented in any of the states in individual, commercial or community buildings. Collecting rainwater from rooftop catchments and putting it in the aquifer is one of the most economical and effective ways of recharging groundwater, especially in zones where urbanization is increasing rapidly.

Areas with impermeable hydrogeology

Central India holds the most impermeable layer of rock in the underground geology. The tough terrains, largely comprising basalt, granite and gneiss, form the hard strata. In these states, natural groundwater recharge is low due to massive hard rock formations.

Madhya Pradesh has seen a steep rise in agricultural production since 2008 due to increase in irrigation facilities based on groundwater sources. Cities such as Indore, Khargone, Dewas, Gwalior and Tikamgarh have witnessed decline in groundwater levels. According to the 2021-22 Central Groundwater Board Yearbook, twenty-four out of 459 blocks in Madhya Pradesh are overexploited.

Jharkhand and Chhattisgarh have hard massive layers of impermeable rock which makes natural groundwater recharge difficult. Gujarat and Maharashtra share rain-shadow areas, where rainfall is as low as 400 mm annually, and thus groundwater recharge is very low in these areas.

In such areas, groundwater recharge becomes crucial to meet the requirements of domestic and commercial purposes. Watershed management activities have proven to be the most effective strategy to recharge groundwater in these states. A key point to be noted is that since the underlying geology is mostly massive in Jharkhand, Chhattisgarh, Madhya Pradesh and Maharashtra, identification of lineaments becomes crucial for groundwater recharge systems in these states. In areas with faults or lineaments, structures such as percolation tanks, recharge ponds, recharge shafts, gully plugs, gabions or check dams can be constructed to to reduce the velocity of runoff and make water percolate down to the aquifer.

Table 22: Selection criteria of recharge structures for groundwater recharge

Name of structure	Type of structure	Rock/soil suitability
Staggered contour trenches (SCT)	Soil conservation and groundwater recharge	Sandy soil, sandy loam, weathered rocks,
Continuous contour trenches (CCT)		
Water absorption trenches (WAT)		
Loose boulder check dams (LBCD)	Drainage line treatment and groundwater recharge	Sandy soil, sandy loam, weathered rocks
Earthen gully plugs	Drainage line treatment and groundwater recharge	Sandy soil, sandy loam, weathered rocks
Gabion structures	Drainage line treatment and groundwater recharge	Hard rock, sandy soil, eroded soil, heavy erosion
Percolation tanks	Groundwater recharge	Fractured rocks , sandy or loam soil, weathered rocks
Farm ponds	Rainwater harvesting	Impermeable soil
Sunken ponds	Rainwater harvesting	Impermeable strata
Check dams	Rainwater harvesting and groundwater recharge	Impermeable strata, weathered rocks
Recharge shafts	Groundwater recharge	Fractured rocks

Source: Compiled by CSE

Additionally, rooftop rainwater harvesting systems installed in schools, residential buildings or community or commercial buildings can also help in recharge of groundwater.

Areas with sandy soil

Sandy soil is the most suitable soil for groundwater recharge. It is both porous and permeable and generally forms a part of alluvium deposits and desert soils.

CASE STUDY

Sunken ponds in seasonal streams have increased annual income of farmers in Niwari district, Madhya Pradesh

Issues

Declining water in village Gulenda of Niwari block, Niwari district, Madhya Pradesh, resulted in loss of crops due to lack of irrigation. Small water-channels dry up during the dry season. Though these channels have substantial inflow of water from the upper catchment area of more than 70 hectare, the soil profile and geology don't allow the water to retain for long. Rainwater percolates down the sandy loam soil in the village. There are wells and ponds around the farms, but the community wanted solutions to retain surface water at least for rabi crops.

Wheat, chickpea, mustard and gram are the main crops grown in the village. Vegetables such as potato, onion, brinjal, tomato, ladyfinger and ginger are also grown and require water. The self-help groups (SHGs) have been approaching the gram panchayat and SRIJAN—Self-Reliant Initiatives through Joint Action, a Delhi-based grassroots organization supporting this programme in the village—to fill these gaps so that it can recharge the groundwater and provide irrigation to crops.

Solutions and impact

To handle this challenge of water scarcity for irrigation and groundwater recharge, sunken ponds were constructed in the channels (nalas). The design of sunken ponds is such that a series of ponds of dimensions according to the bed of the channel (usually 10 m x 3 m x 1 m) at an interval of 5–10 metre is constructed. The slope of the bed of channels is not disturbed while construction. A gap of 5–10 metre is given to break the velocity of flowing water, and also to prevent the erosion.

Such a series of ponds has been proved to be useful in tapping surface and sub-surface flow for groundwater recharge and also to irrigate the rabi crop. Five such ponds in a series were constructed in Gulenda village, creating water capacity of 150 cubic metre (150,000 litre). The water also provides for drinking needs of livestock. Around 20 acre of land is irrigated through these sunken ponds by tapping sub-surface flow, benefitting 10 families. According to the farmers in the village, due to the sunken ponds, 20 per cent more area has been brought under cultivation, which generates additional income to the families. More such sunken ponds have been planned to be constructed in the village and nearby areas where more water is required for irrigation. The operation and maintenance of these sunken ponds is done by the Water User Groups (a group of people using water from these ponds).


PHOTO CREDIT: PRADEEP KUMAR MISHRA

A sunken pond constructed in Gulenda village in Niwari district, Madhya Pradesh


PHOTO CREDIT: PRADEEP KUMAR MISHRA

Beneficiaries of the sunken ponds in Gulenda village

CASE STUDY

Revival of ponds in Dharwad district, Karnataka, to improve groundwater storage in water-scarce areas

Background

Groundwater is the major source of drinking water in villages of Dharwad district in north Karnataka. Groundwater levels are fast declining in the state, with 34 talukas considered critical due to overexploitation. Factors such as population pressure, effluent discharge and addition of agricultural chemicals into soil have contributed to deterioration of groundwater quality and plunging groundwater levels.

Dharwad district has an area of 4,273 square kilometre. It grapples with water scarcity due to erratic rainfall, absence of a perennial surface-water source, and declining groundwater levels. In a good rainfall year, the groundwater is able to meet the requirement. In poor rainfall years, however, the community faces extreme hardship to meet drinking requirement. Analysis of India meteorological rainfall data for five years (2016–20) in Dharwad district shows that 2016, 2017 and 2018 received rainfall much below the average annual of Karnataka (1,200 mm) (see *Graph 6: Rainfall pattern in Dharwad district*). Since the district sits on hard and massive rock, the chances of natural recharge are also limited. Being a groundwater-dependent region, the community faces acute shortage of water in summers due to the drying of the wells, and women have to walk 2–3 km every day to fetch water.

The change

Dharwad district has various natural ponds and lakes in the villages. These were earlier the source of water for the community. However, over the years, these ponds were abandoned due to encroachment, silting and lack of operation and maintenance as communities started exploring water from borewells, and soon the natural ponds lost their glory.

Once revived, these ponds, located in depressed areas of villages, proved to be groundwater-recharge bodies. The region lacks perennial sources of surface water, and as of now there has been no provision to get surface water. The region has no perennial rivers but has several ponds that were revived and now contribute to groundwater recharge.

The Rural Drinking Water and Sanitation Department (RDWSD) of Karnataka, which is working towards ensuring sanitation and providing clean drinking water to rural areas, decided to revive the natural ponds that already existed in the villages to increase their efficacy and efficiency for rainwater harvesting and sub-surface recharge. The identification of ponds was done on specific defined parameters so as to get maximum impacts in the limited resources available. Priority was given to ponds that can be restored close to their former condition to serve as groundwater recharge bodies at the village level.

Jal Jeevan Mission (JJM) was implemented in 2020 in Guddad Hulikatti village in Kalghatgi taluk. Before it was launched, the community depended on borewells and drew water for their needs through the community standpost. In the same year, the panchayat decided to desilt the non-functional natural pond to enhance its water-impounding capacity. The revived pond is spread over an area of 25–30 acre. Near the pond, a 90-metre-deep borewell was drilled. Since the pond now, after revival, has water throughout the year, it facilitates recharge of groundwater. The borewells away from the revived ponds also supplied water during peak summers due to good recharge of groundwater. Harvested water recharged also serves as a buffer resource in years of low rainfall. Similarly, the natural pond spread in an area of 10 acre in Chalamatti village in Kalghatgi taluk was also revived and a 120-metre-deep borewell was constructed near the pond.

Operation and maintenance

Groundwater extracted through borewells are the source of drinking-water supply in rural areas of Dharwad. Under Jal Jeevan Mission, groundwater sources are being recharged and augmented by revived ponds, which act as village-level groundwater recharge structures. Water from the borewells is pumped and stored in overhead tanks. For example, in Guddad Hulikatti village a 50,000-litre-capacity tank was constructed. From the overhead tank, water is distributed to the community through a 2,920-metre-long network of pipelines to functional household-tap connections. The usage quantity provisioned is for 55 litre per capita per day for a population of 1,518 (see *Figure 16: Rural water supply distribution system in villages of Dharwad district*). Similarly, in Chalamatti village, a 50,000-litre-capacity overhead tank with a 3,700-metre-long distribution network caters to the drinking water needs of the community of 1,300 persons.

To ensure capacity enhancement of ponds in the future, the gram panchayat will, using panchayat funds, deepen and desilt the ponds every alternate year. Every village has a Village Water and Sanitation Committee (VWSC) looking after the operation and maintenance of the distribution network. To ensure the water quality of the source is as per the prescribed standards, every gram panchayat is provided with field testing kits and has been trained by the officials of Rural Drinking Water and Sanitation Department. Dharwad also has district laboratory where periodical monitoring of the supplied water quality has been undertaken.

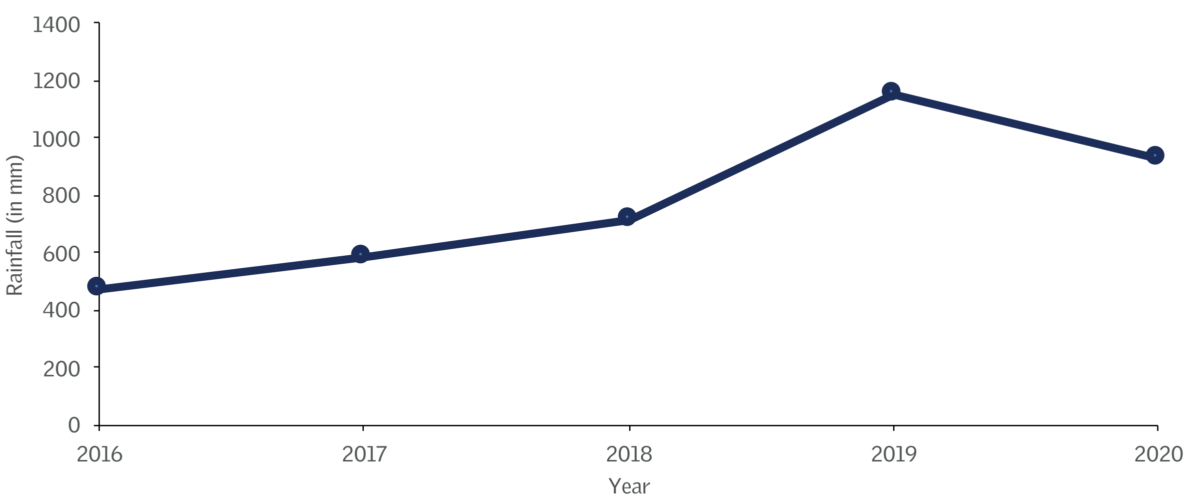
"Ten to 15 years ago, the water supply in the village was good. It was accessible through the community standpost and we never had any problems with availability of water. Around five to six years ago, groundwater levels began to decline and there was no water in the summer months either for drinking or other domestic needs. We had to wait for two or three days to get water supply. In the last two years, the water situation in the village has improved. We are now getting a regular supply of water through taps in our houses. We get a one-hour supply in morning and another hour's supply in evening. Even if there is a power cut, we get water at the scheduled time—this never happened before.

—Rustam Saab Nabil, age 71, resident of Guddad Hulikatti village, Kalghatgi taluk, Dharwad

"The villagers are happy as they are getting adequate water for their needs. It is important to ensure the quality of water is as per recommended standards. We have been provided with field testing kits by the gram panchayat. We use these to monitor the quality of water every 15–30 days for the source and endpoint of distribution network. We measure parameters such as TDS, hardness, pH, alkalinity, nitrate, fluoride and iron."

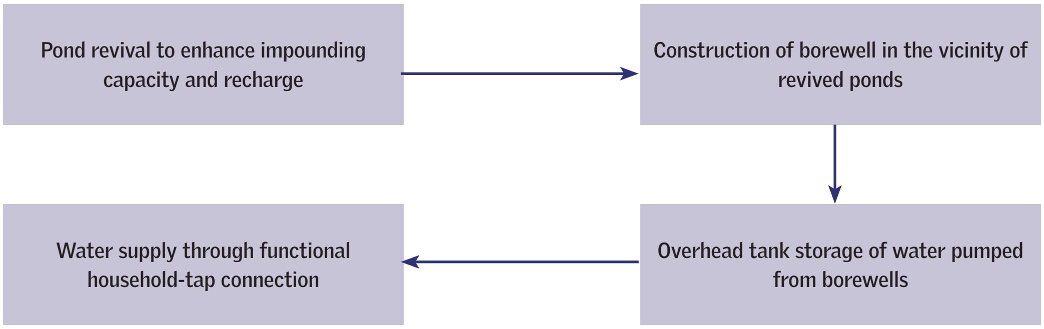
—Jagdish, age 29, VWSC member, Guddad Hulikatti village

Graph 6: Rainfall pattern in Dharwad district (2016–20)



Source: Indian Meteorological Department, https://hydro.imd.gov.in/ as viewed on April 8, 2022

Figure 16: Rural water supply distribution system in villages of Dharwad district



Source: Compiled by CSE

PHOTO CREDIT: FARAZ AHMAD

Public standpost for water supply in Guddad Hulikatti village, Kalghatgi taluk, Dharwad

PHOTO CREDIT: FARAZ AHMAD

Revived pond in Guddad Hulikatti village, Dharwad district

PHOTO CREDIT: FARAZ AHMAD

Functional household-tap connection in Chalamatti village, Dharwad district

CASE STUDY

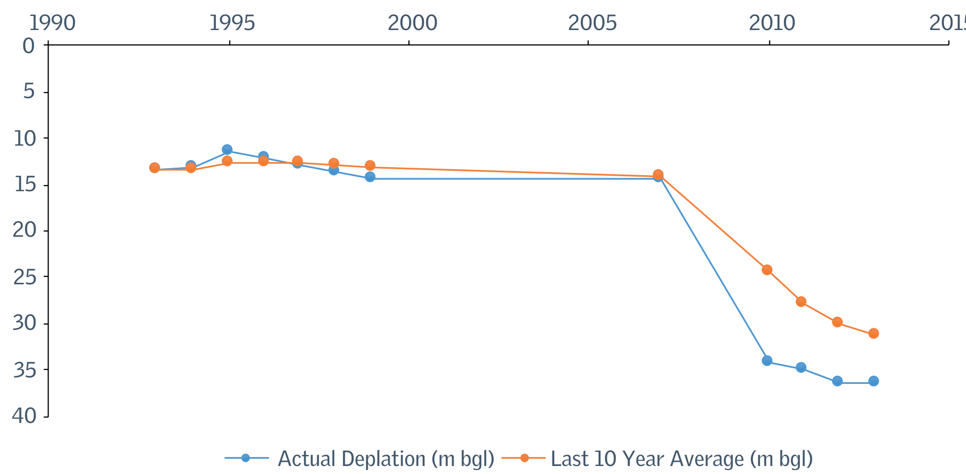
Rooftop rainwater harvesting system in water-stressed areas of Barmer district, Rajasthan

Background

Jagsa village, located in the eastern part of Balotra block in Barmer district, had no source of drinking water. The groundwater in the village is mostly saline, and salinity affects agriculture as well as human health.

The village receives just 284 mm of annual rainfall. The high dependence on groundwater for irrigation since 2007 caused groundwater levels to fall to a depth of 34.77 metre below ground level in 2010 (see *Graph 7: Groundwater levels of Balotra block [1993–2013]*). Falling groundwater levels was associated with significant reductions in crop yield and cropped area, and also led to migration of villagers to Maharashtra and Gujarat for their livelihood.

Graph 7: Groundwater levels of Balotra block (1993–2013)



Source: www.indiawris.gov.in

> "Getting drinking water was challenging in the village as there was no source of either surface or groundwater for drinking needs. So for drinking water the villagers depended on tanker supply from the nearby town Balotra, nearly 20 km from the village. This cost Rs 2,000–3,000 per tanker. On regular days, one tanker of water was enough for a single family for a month, but in summers the requirement increased to three tankers a month, which cost up to Rs 6,000–9,000 per family per month. More than 20 villages in the block faced the same issue."
>
> —Vivek Gupta, Executive Engineer, Watershed and Soil Conservation Department

Plan

The Watershed and Soil Conservation Department took the initiative to address the issue of water supply. Under the Integrated Watershed Management Programme (IWMP)–16,[1] sanctioned in 2009–10, the department decided to construct a 45,000-litre tanka for selected farmers along with rooftop rainwater harvesting structures in their house premises mainly for storing drinking water. For the purpose of irrigation, there was also provision in agriculture fields for constructing a 100,000-litre tanka with agor (a sloping-surface platform or catchment area, or tank's water catchment area from where rainwater is collected) to collect rainwater.

To help locate feasible locations for constructing tanka in the village, department officials along with villagers did a village transect walk. A village watershed committee was formed for regular operation and maintenance of the structures. A detailed project report was prepared with the help of villagers and verified by a state-level committee.

Construction of a 30,000–45,000-litre tanka costs around Rs 1–1.25 lakh and a 100,000-litre one costs Rs 1.5-1.75 lakh. Funds from the Integrated Watershed Management Programme (IWMP) and Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) were used for construction and for operation and maintenance.

Impact

Construction of rooftop rainwater harvesting structures helps beneficiaries collect rainfall in tankas. The collected water can be used for drinking for a whole year. Also, the collected water is pure in comparison to groundwater.

Construction of tankas reduced dependency on tankers and groundwater for beneficiaries. Households who were dependent on tankers were now saving up to Rs 8,000–10,000 per month (for a family of four to five people) and time and were getting water at their home premises. For the purpose of irrigation, villagers use another tanka constructed on their farmland.

In 2010–11, under the National Agriculture Development Scheme launched in 2007, the Horticulture Department started a fruit production scheme for interested farmers. In 2011, only 16 farmers were interested in the scheme. The department also started pomegranate cultivation on 32 hectare of farmland using the watershed tanka scheme.

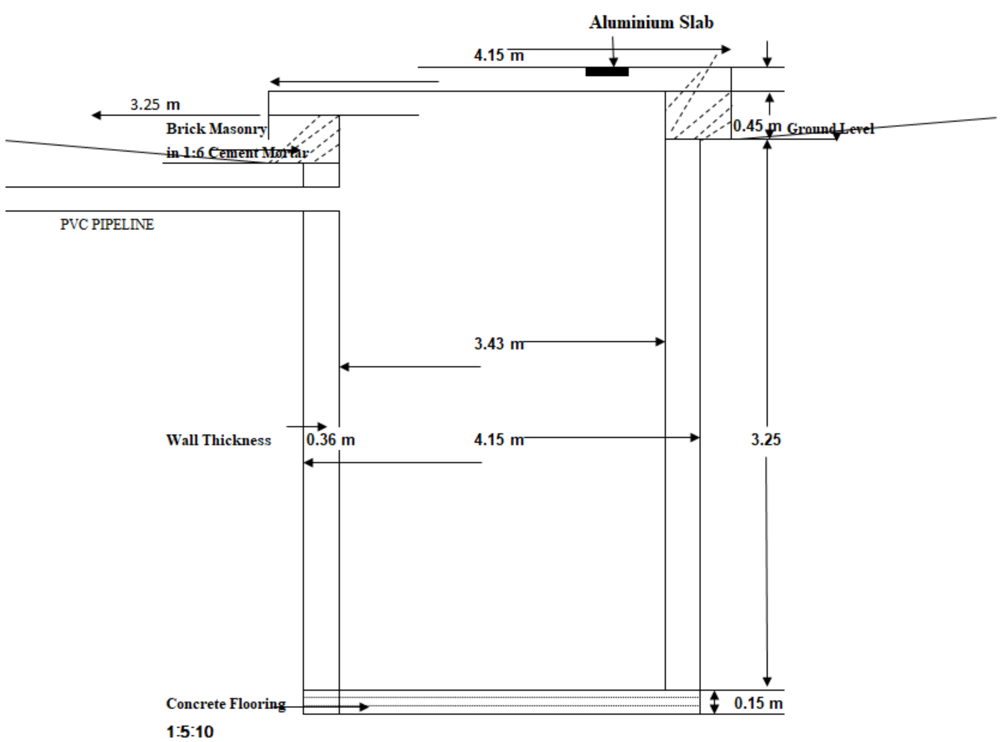
The model was very successful among the farmers. Currently, more than 1,125 farmers cultivate pomegranate on an area of 3,200–3,300 hectare across Balotra block.

Departments such as the Horticulture Department promoted drip irrigation, which helped farmers save water and time. Tapping rainwater helps villagers greatly as water conservation and irrigation are more sustainable. Currently, farmers get an average yield of Rs 5 lakh per hectare per annum. Previously, yield was 90,000–100,000 per annum.

Specifications

The tanka has a diameter of 3.43 m and height of 3.43 m. It has a storage capacity of 30,000 litre. Its walls are constructed with brick masonry of 0.36 m thickness. The flooring is of cement and has a thickness of 0.15 m. The tanka is provided with a parapet of 0.45 m. An aluminum slab is used to cover the tanka (see *Figure 17: Illustration of tanka construction*). The design of tanka was suggested by the Department of Watershed and Soil Conservation and is widely used in the region.

Figure 17: Illustration of tanka construction



Source: Compiled by CSE

"Earlier my family got water for drinking from a tanker, which cost Rs 3,000 per month. There was no reliable source to irrigate my farmland. But construction of the rooftop rainwater harvesting structure and the tanka by the Watershed Department in 2012–13 helped my family get enough drinking water through the year. For agricultural needs, I used another tanka in the field for pomegranate cultivation. Earlier my annual income was Rs 1–1.2 lakh but after construction of tanka and through pomegranate farming I can generate a profit of around Rs 5–5.5 lakh annually.

— Anchla Ram Ranchod Ram, age 50, farmer in Jagsa village, Balotra block

PHOTO CREDIT: VIVEK KUMAR SAH

Rooftop rainwater-harvesting system connected to a tanka, Budiwada village, Barmer district, Rajasthan

CASE STUDY

Khadin secures freshwater for farmlands in salinity-affected Barmer district and results in groundwater recharge

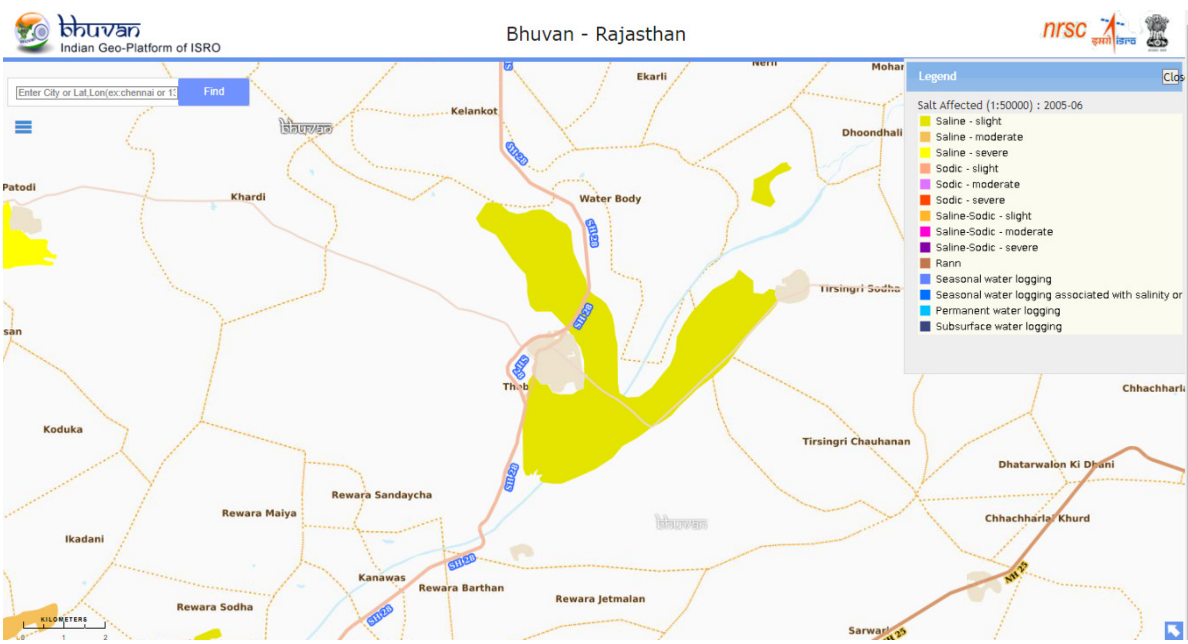
Background

Village Thob is located in Balotra tehsil of Barmer district. Its groundwater and surface water both had high levels of salinity in (see *Figure 18: Planning of work through Bhuvan portal*).

Geologically, a part of Balotra block is covered by formations of hard rock such as rhyolite and granite. These have poor water-yielding capacity.

Balotra developed as an industrial centre for textile processing. The textile-processing industry generates effluents, which contain toxic elements that lead to high levels of salinity in both groundwater and surface water. Salinity in some areas such as Thob and Pachpadra is very high—the value of total dissolve solids (TDS) is around 4,000 part per million (ppm).

Figure 18: Planning of work through Bhuvan portal



Source: www.bhuvan.nrsc.gov.in, accessed on January 10, 2023

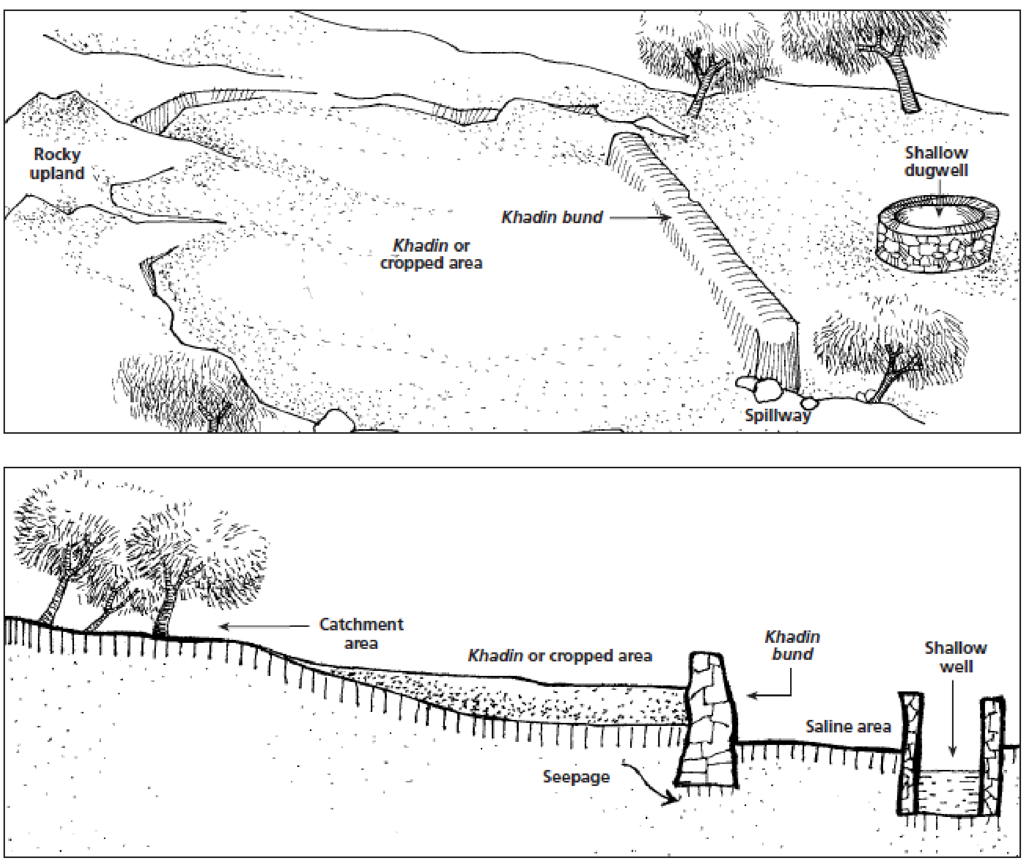
Groundwater in the village as it is found at a depth of 15 metre. The high salinity had a major impacts on crop production and led to health complications such as cardiovascular disease, diarrhoea and abdominal pain. The consequent reduction in annual income led to large-scale inter-district and inter-state migration.

Plan

In 2013, after years of grappling with the problem of groundwater salinity, Daula Ram, a farmer from Thob village, along with the village sarpanch and other member of the village administration approached Department of Watershed and Soil Conservation officials to address the issue.

The officials visited the village and had a meeting with community members. They decided to construct a khadin, a traditional water-harvesting structure (see *Figure 19: Illustration of a khadin*) for water conservation and groundwater recharge. After all the administrational and financial sanctions, a khadin was constructed

Figure 19: Illustration of a khadin



Source: Anil Agarwal and Sunita Narain (ed.) 1997, *Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems*, Centre for Science and Environment, New Delhi in the village near Daula Ram's farmland. In 2014, three 3-km-long khadin were constructed in the village. The khadin also work as a barrier that protects fields from surface salinity of other fields.

Impact

As rainfall is scanty in the region, the khadin is a saviour for the villagers as its not only conserves water but also helps to recharge the groundwater. After construction of the khadin in the village, farmers like Daula Ram, Mahipal Singh, Salgaram and Karan Singh began to grow more crops than they previously grew. Farmer Daula Ram said that 15 years ago he was not able to grow half of the crops he is growing now. "The main problem was waterlogging near my agricultural field, which caused salinity and affected my agricultural production. But the khadin works likes a barrier between the agricultural fields and waterlogged area," he said.

"A decade ago, due to high levels of salinity on my farmland I was not able to grow a single crop. The land also became less fertile, which caused me huge losses. I migrated to Gujarat for my livelihood. But in 2014, the construction of the khadin changed my life. I am now able to get two crops a year. The khadin is a saviour for me and my family. My annual income has increased, and now I am able to send my children to good schools for higher education."

—Daula Ram, age 53, Thob village, Balotra block

PHOTO CREDIT: VIVEK KUMAR SAH

A khadin in Thob village, Barmer district, Rajasthan

Whenever the monsoon is below normal, water accumulation in the lower reaches of the khadins is poor, and crops such as pearl millet and cluster beans are grown during the kharif season. If the monsoon is good, stored water can also be used for the cultivation of rabi crops such as wheat, mustard and chickpea either as sole or mixed crops using conserved soil moisture. When there is good rainfall during the monsoon, water from the khadin can be used for nearly three months.

The construction of the khadin was carried out by the Watershed and Soil Conservation Department under the Integrated Watershed Management Plan (IWMP). The total cost was Rs 19.96 lakh. The department closely monitors all the operation and maintenance with community participation.

Chapter 5: Designing different groundwater recharge structures

- Designing of groundwater recharge structures should be based on rainfall, physiography, drainage, soil and geology of the area.
- Watershed management has proved to be one of the most effective ways of improving the quantity and quality of groundwater in different ecological regions.

We have so far discussed the type of groundwater recharge structures suitable for specific hydrogeological areas. This chapter deals with the sizing of structures.

Rainwater needs to be stored through recharge in aquifers. The process of recharge is much slower than the rate of extraction. The structures constructed for the purpose of recharge need to be technically fit and efficient enough to infiltrate the surface runoff to aquifers. The efficiency of structures depends on their suitability and design based on surveys and hydrogeological considerations. The structures are designed for hydraulic and hydrologic strengths so that they can withstand the pressure of water and serve the purpose for which they were built.

Designing a recharge structure

Design considerations comprise various parameters, including rainfall, soil structure, soil texture, hydrogeology, availability of land, physiography, drainage, slope and availability of funds. As this chapter deals with groundwater recharge (hydraulic) structures, the calculation of parameters (design) will incorporate inflow of the runoff that percolates down for recharge.

Some design considerations are:

a. **Hydrologic considerations**: Rainfall, runoff and temperature
b. **Hydraulic considerations**: Density and unit weight of construction materials
c. **Environmental considerations**: Submergence area, habitations, local ecology, and flora and fauna

While it is important to keep all the design parameters in mind while designing groundwater recharge structures, we will focus on hydrologic considerations and calculation of recharge parameters to give a sense of the pre-calculations in

SOME TECHNICAL DEFINITIONS

Catchment area: A catchment is an area that catches rainwater and drains it through a single outlet.

Time of concentration: The time taken by rainwater from the remotest point of the catchment to reach the outlet of water.

Surface runoff: Running rainwater on the ground surface after the percolation of rainwater into the soil.

Peak runoff: The runoff generated after the highest intensity of rainfall is received in the watershed.

designing the structures. Hydrologic design evaluates the total inflow of runoff to the groundwater recharge structure and its strength to withstand the pressure of runoff.

Structures for groundwater recharge

The watershed approach—in which the treatment and recharge interventions are done from the ridge to the valley of the watershed—is used to recharge groundwater in any village.

The first step is to start the intervention in higher elevations and areas with high slopes at the ridge of the watershed. Second, intermediate areas, where the slope is less and agricultural land starts, are treated and groundwater recharge activities are done here. Last, groundwater recharge structures are planned at the lowest elevation.

This toolkit discusses recharge structures in the following three categories:
a. **Recharge at ridge areas (higher slopes)**
b. **Recharge through drainage lines (stream network)**
c. **Other structures for groundwater recharge and rainwater harvesting**

Through these interventions, effort is be made to catch every drop of rain in the watershed where it falls so that it percolates to the subsurface to reach the groundwater. The technical aspects of these structures are crucial. Any error in designing these structures may lead to incorrect implementation, which may create problems.

We shall now discuss each of the structures.

Recharge in ridge areas

The ridge of a watershed can have a slope of from 15–20 per cent to more than 40 per cent, including steep hillocks. Due to high slopes, these areas have a very high velocity of runoff and hence any groundwater recharge structure is not recommended. Also, ridges are prone to landslides and heavy erosion and they often have forest plantations. Such areas are recommended for dense plantation works. The dense canopy of forestation does not allow the erosion of soil due to impact of rainwater and contributes maximum into surface runoff.

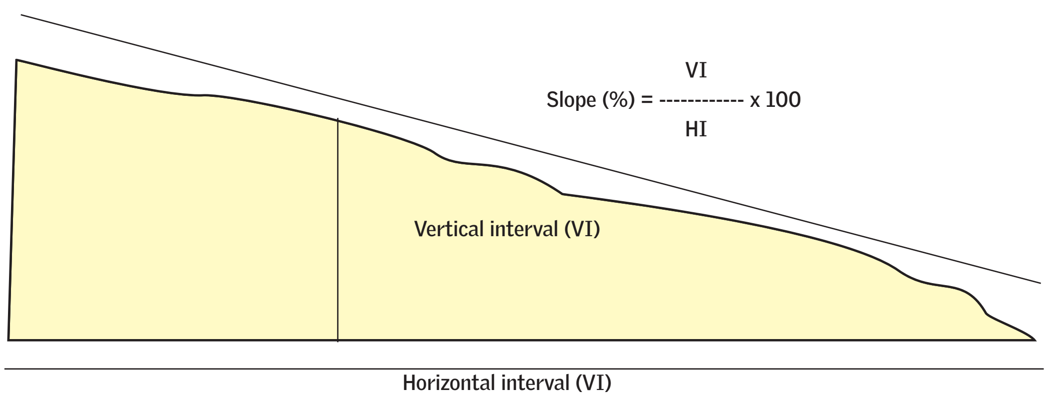
Staggered contour trenches (SCT)

Trenches are structures in the form of rectangular pits, constructed in the upper catchment where the slope is in the range of 15–25 per cent. In the ridge-to-valley approach, trenches are the first structures of area treatment in any watershed.

There are two kinds of structures proposed for treatment in upper catchment areas with high slopes—staggered contour trenches (SCT) and continuous contour trenches (CCT). Since the trenches are constructed by digging soil along the contour lines and no masonry or concrete work is involved, a slight mistake in identification of contour lines can create damage to the land Hence, SCT is preferred over CCT in such cases as mishandling of runoff is prevented and rainwater is conserved for groundwater recharge.

To design contours, it is important to know the slope of the area as these structures are constructed across the slopes. The degree of slope defines the spacing of rows of trenches (see *Figure 20: Representation of a slope*). The steeper the slope, the less is the gap between the rows of trenches across the slope and vice versa.

Figure 20: Representation of a slope



Source: Compiled by CSE

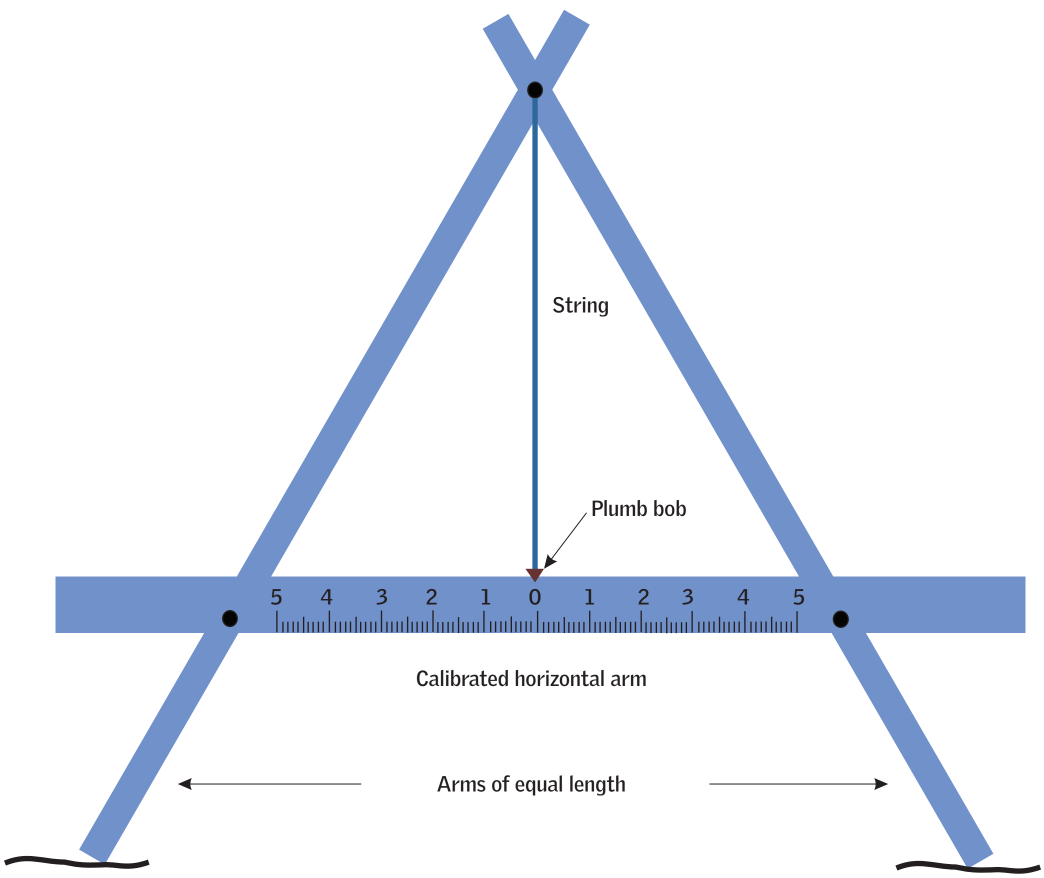
The measurement of the slope of terrain can be done by either using advanced instruments such as theodolite or total station (a surveying instrument) or by simple instruments like an A-frame level or a pipe level. The latter technique is used broadly for easy work in watershed management by communities. Pipe-level instruments are easy to understand and complete the work faster than A-frames.

A-frame

As the name indicates, an A-frame is a simple instrument made with wooden sticks by arranging them in the form of the alphabet A. The base of the structure (horizontal leg) is marked with a scale with 0 at the centre. A string with a plumb bob is attached from the apex of the structure to the scale. An A-frame is the easiest tool to mark the slope of hilly areas (see *Figure 21: Illustration of an A-frame*)

The first point on every row is decided by the surveyor, and one leg of an A-frame is kept on that point. The next point of elevation equal to the first one is then

Figure 21: Illustration of an A-frame



Source: Compiled by CSE

searched by moving the second leg, keeping the first leg fixed. The point where the plumb bob reading is 0 is the point of equal elevation. The second leg is kept fixed at the second point. The first leg is lifted, with the second leg firm kept at the located point, and the A-frame is rotated around the second leg to find the next point of equal elevation. The process is repeated till all the area is demarcated with contour lines.

Pipe level

A pipe level is another simple instrument used to calculate slope and find the contours of a terrain. The instrument consists of two calibrated vertical wooden flat strips that have pipes attached to them at the same level. While using the instrument, water is filled in the pipes and readings are recorded for the slope or to find the contours.

To find the contours, one strip is fixed at a point, and the other one is kept at a distance where the same elevation is to be found (at a fixed interval, say 5 metre). Once the water levels in the scale read the same number, the point is of the same elevation. The process is repeated, and points of same elevation are observed and marked. Finally, all those points are joined, and the contour line is visible. The same process is repeated at another vertical interval of contour value.

To find the slope of the terrain, one strip is kept at a higher elevation while the other is kept at a lower elevation (points between the slope). We record the water level in both the pipe ends in the strips. Also, the horizontal difference between both the strips is measured by means of a metric tape.

The slope is calculated using the following formula:

$$\text{Slope (\%)} = \frac{\text{Reading difference between both pipe levels}}{\text{Horizontal distance between both strips}} \times 100$$

Example:
A piece of land is to be surveyed by means of a pipe level. The reading of the strip at the lower elevation is 5 metre and that of the higher elevation is 2 metre. The distance between both strips is 15 metre.

Reading at lower elevation (A)	=	**5 metre**
Reading at higher elevation (B)	=	**2 metre**
Distance between both strips (D)	=	**15 metre**

The equation for finding the slope from pipe level is:

$$\text{Slope (\%)} = \frac{\text{Reading difference between both pipe levels}}{\text{Horizontal distance between both strips}} \times 100$$

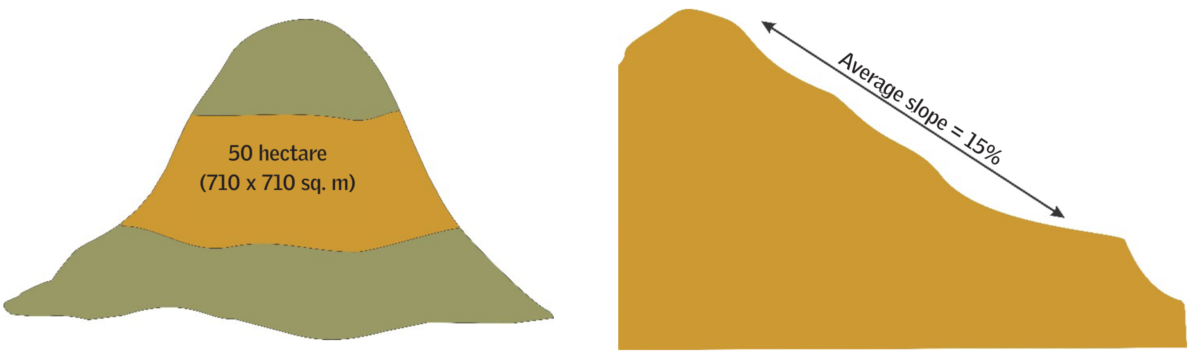
$$\text{Slope (\%)} = \frac{B-A}{D} \times 100$$

$$\text{Slope (\%)} = \frac{5-2}{15} \times 100$$

Slope of the terrain = 20%

Example:
The layout trenches for an area of 50 hectare (equal stretch in length and breadth) of uphill land where the average slope is 15 per cent is to be designed. Rainfall for a maximum of six hours with a return period of five years in the area is 100 mm. The runoff coefficient of the area is 0.4. The trenches get filled twice a day.

We can assume the dimensions of trenches in practice to be 3 x 1 x 0.6 cubic metre.



Source: Compiled by CSE

In this case, the area of the land is 50 hectare, stretched equally in length and breadth, which means that the land is square-shaped.

The surface runoff (SRO) generated in the area can be calculated as follows:

SRO = A x R x C

where,

SRO	=	Surface runoff in cubic metre
A	=	Area in square metre
R	=	Average rainfall in metres (for 25–30 years)
C	=	Coefficient of runoff

Let us convert all parameters in one unit, i.e. metre

Area	=	50 hectare
	=	500,000 square metre

Average slope (S) of the site = 15%

The SRO of the area is calculated as follows:

$$\begin{aligned} SRO &= A \times R \times C \\ &= 500{,}000 \times 0.1 \times 0.4 \\ &= 20{,}000 \text{ cubic metre} \end{aligned}$$

We assume that only 70 per cent of the total generated SRO will be trapped in the trenches. So the effective surface runoff (ESRO) will be:

$$\begin{aligned} ESRO &= 0.7 \times SRO \\ &= 0.7 \times 20{,}000 \\ &= 14{,}000 \text{ cubic metre} \end{aligned}$$

Now, we calculate the volume of one trench (V_t). The dimensions as given in the example are as follows:

L = 3 m, B = 1 m, D = 0.6 m

$$\begin{aligned} V_t &= 3 \times 1 \times 0.6 \\ &= 1.8 \text{ cubic metre} \end{aligned}$$

Since the trench will get filled twice a day, effective volume of the trench (V_{te}) is:

$$\begin{aligned} V_{te} &= 2 \times V_t \\ &= 2 \times 1.8 \\ &= 3.6 \text{ cubic metre} \end{aligned}$$

The tentative number of trenches (N) required in the area can be calculated is:

$$N = \frac{ESRO}{V_{te}}$$

Putting the values:

$$N = \frac{14{,}000}{3.6}$$

$$= 3{,}889$$

Effective length of one trench (L_e) = Length of trench + distance between two trenches

$$\begin{aligned} &= 3 + 2 \\ &= 5 \text{ metre} \end{aligned}$$

Total length of trenches (L_t) $= N \times L_e$

$= 3,889 \times 5$

$= 19,445$ metre

$$\text{Spacing between rows of trenches} = \frac{\text{Area of land (A)}}{\text{Total length of trenches}}$$

$$= \frac{500,000}{19,445}$$

$= 25$ metre

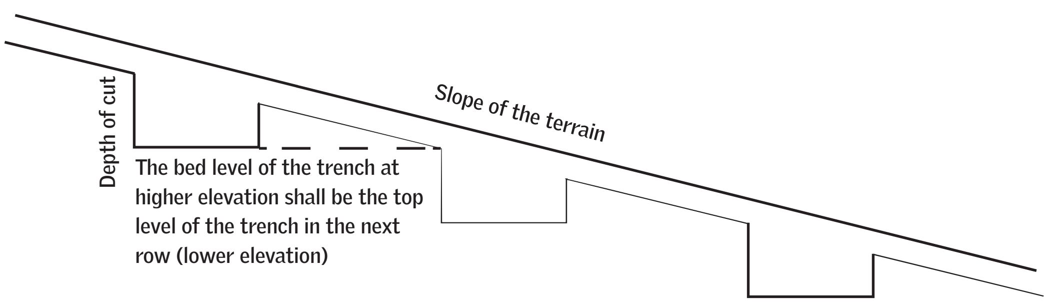
$$\text{Number of rows of trench} = \frac{\text{Longest length of the land along the slope}}{\text{Spacing between two trenches}}$$

$$= \frac{710}{25}$$

$= 28$ rows

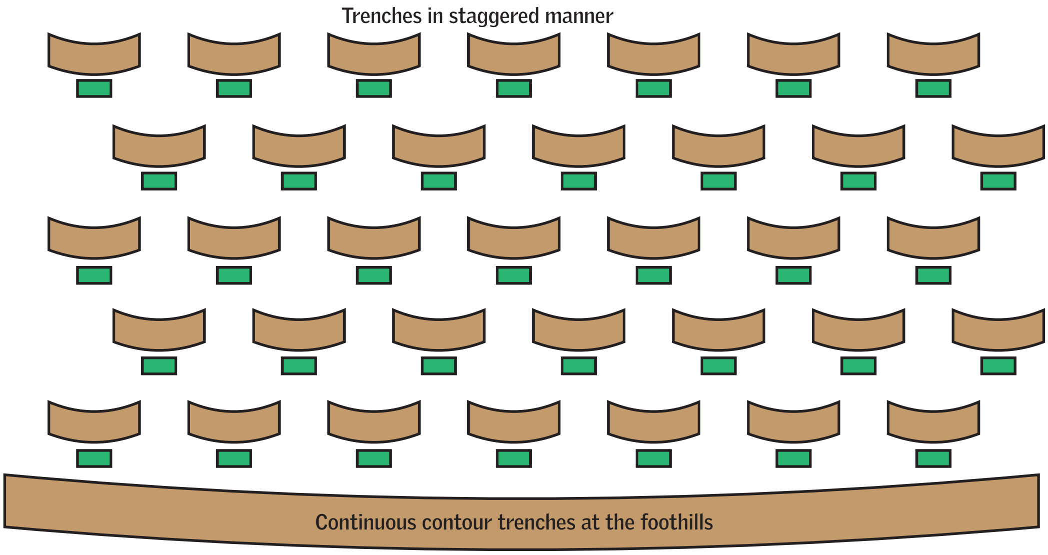
Figure 22 shows the typical example of SCT and CCT construction. The rows of trenches are arranged so that runoff which cannot be captured by previous rows or overflow is captured by the trenches in next rows. Additionally, a CCT is constructed at the end of SCTs, where overflow from all SCTs are captured for groundwater recharge.

Figure 22: Slope and cut fill for SCT



Source: Compiled by CSE

Figure 23: Illustration of plan view of staggered contour trenches



Source: Compiled by CSE

Recharge through drainage lines

A watershed has a network of streams, starting from the ridge to the valley. The rainfall in the watershed runs through these streams, which joins and forms higher-order streams. It is vital for a watershed to demarcate different orders of streams, and runoff is checked at each order to augment the groundwater below through the subsurface flow.

Loose boulders check dam and gully plugs

Loose boulder check dams (LBCDs) are low-cost structures constructed on first- and second-order streams that have a catchment area of 2–50 hectare. These low-cost structures help reduce the velocity of runoff and conserve the soil in drainage lines. The structures are constructed with locally available medium-sized boulders. Their construction is restricted to areas where boulders are available.

A catchment of more than 20 hectare would generate more volume of water and the cumulative pressure of runoff can break the structure.

Gully plugs can be constructed in areas where there are not enough boulders. In such areas, gully plugs can be made using soil and compacting it for strength. The only difference between an LBCD and gully plug is the construction material used.

To calculate the peak discharge through the channel where a gully plug or LBCD is constructed, the following formula is used:

$$Q = A \times R \times C$$

where,

Q	=	Peak discharge in cubic metre per second (cumec)
A	=	Area of catchment in hectare
r	=	Intensity of rainfall, in millimetres per hour (mm/hour)
C	=	Coefficient or runoff (can be referred to Strange's table of runoff coefficient)

On the basis of peak discharge calculated, the dimensions of the LBCD or the gully plug can be calculated.

While constructing a gully plug, it must be kept in mind that since it is an earthen structure, an outlet such as a waste weir should be provided for safe disposal of water. An LBCD, on the other hand, is made of boulders and water flows over it, so it does not require another outlet.

A loose boulder check dam (LBCD)

Sizing of LBCD

To draw the LBCD on a graph or paper, calculations are done to get the volume of the structure. The height of the structure is decided (the rule of thumb is 1 m in smaller streams) during the field survey of the stream at each chainage and other calculations are done accordingly. (To calculate volume, see *Table 23: Format to calculate LBCD's quantity.* Other dimensions are given here for reference.)

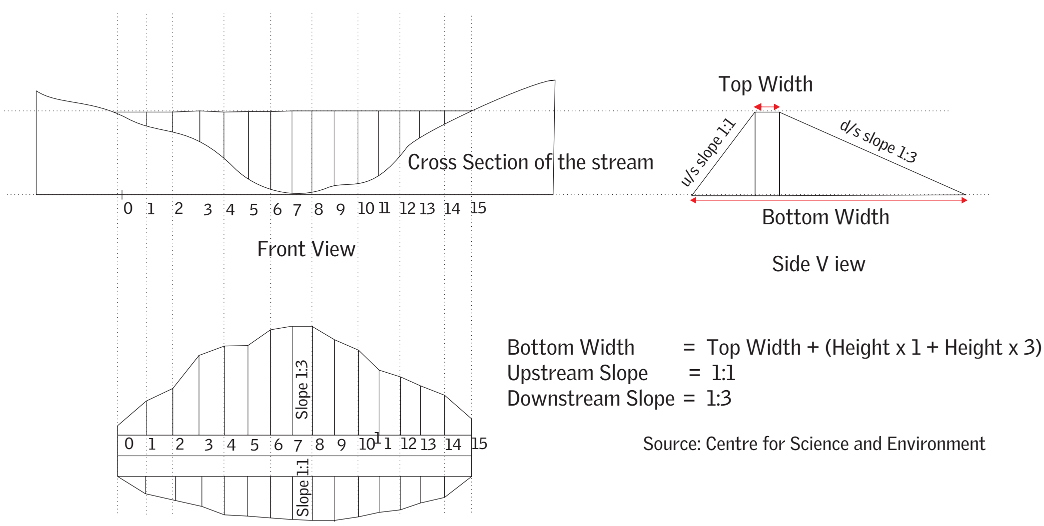
Table 23: Format to calculate LBCD's bill of quantity (BOQ)

S. no.	Chainage	Top width (TW)	Height (H)	Bottom width (BW) = TW + H x 1 + H x 3	Area = 0.5 x (TW + BW) x H	Mean area (A_m)	Distance (D)	Volume (V) = A_m x D
1								
2								
3								
4								
All dimensions in metric units								

After getting details of TW, BW, A_m and V, the drawing of the structure is made on paper or on softwares such as AutoCAD, Civil 3D, Revit or Microsoft Excel.

The drawing of an LBCD is prepared for all the three views, namely front view, side view and the top view (plan). The front view contains a cross-sectional image of the stream on which the structure is made. The side view shows the cross-sectional view of the structure while the top view or plan view shows the placement of the structure in the stream (see *Figure 24: Different sections views of an LBCD*).

Figure 24: Different section views of an LBCD



Source: Centre for Science and Environment

Cost estimate of loose boulder check dam

The cost estimate of an LBCD is simple as the structure is homogenous and made of locally available boulders. The boulders can be collected at the site from nearby areas, and the structure is constructed. A table for the bill of guantity is given in the previous section (see *Table 24: Format to calculate estimated cost of an LBCD*).

Table 24: Format to calculate estimated cost of an LBCD

S. no.	Item no. from schedule of rates (SOR)	Description (as per SOR)	Quantity (from BOQ)	Unit	Rate	Amount
1						
2						
3						
4						
5						
			Subtotal (A)			
			Transportation charges (B)			
			Contingency (C)			
			Grand total (A + B + C)			

Source: Compiled by CSE

Example:

A second-order stream runs through a high-slope terrain. The average bed slope of the stream is 5 per cent. The length of the stream on which the LBCD is to be constructed is 200 metre. Find the suitable number of LBCDs. The survey details of the cross section of the stream are given in the following table. Prepare the design and estimate of the LBCD with the given data.

(All measurements are in the International System [SI] of Units).

S. no.	1	2	3	4	5	6	7	8	9	10
Chainage	0	2	4	6	8	10	12	14	16	18
Height	0	0.41	0.50	0.65	0.85	0.98	0.82	0.6	0.39	0

Solution:

Stream order	:	Second
Bed slope of stream	:	5 per cent
Length of stream	:	200 metre

As we know, the height of the LBCD is sufficient at 1 metre. So we keep the LBCD's height at 1 metre and will make the design accordingly.

Now, the slope (S) is 5 per cent and vertical interval (VI) is 1 metre, which is the height of the LBCD.

Using the formula

$$S = \frac{VI}{HI}$$

$$\frac{5}{100} = \frac{1}{HI}$$

$$HI = \frac{100 \times 1}{5}$$

$$HI = 20 \text{ metre}$$

This means that the tail water stored for each LBCD will be for 20 metre.

Now, let us calculate effective width of the LBCD. From the table, the maximum height is 0.98 m. The upstream slope of the structure is 1:1 while the downstream slope is 1:3. Let us calculate the base width of structure at each chainage.

Chainage	Height	Top width (TW)	Bottom width (BW) = TW + H x 1 + H x 3	Area = 0.5 x (TW + BW) x H	Mean area (A_m)	Distance (D)	Volume (V) = A_m x D
0	0.00	0.30	0.30	0.00	0.00	0.00	0.00
2	0.41	0.30	1.94	0.46	0.23	2.00	0.46
4	0.50	0.30	2.30	0.65	0.55	2.00	1.11
6	0.65	0.30	2.90	1.04	0.85	2.00	1.69
8	0.85	0.30	3.70	1.70	1.37	2.00	2.74
10	0.98	0.30	4.22	2.21	1.96	2.00	3.91
12	0.82	0.30	3.58	1.59	1.90	2.00	3.81
14	0.60	0.30	2.70	0.90	1.25	2.00	2.49
16	0.39	0.30	1.86	0.42	0.66	2.00	1.32
18	0.00	0.30	0.30	0.00	0.21	2.00	0.42
Maximum width of LBCD (in metre)			4.22	Total quantity of LBCD (in cubic metre)			17.95

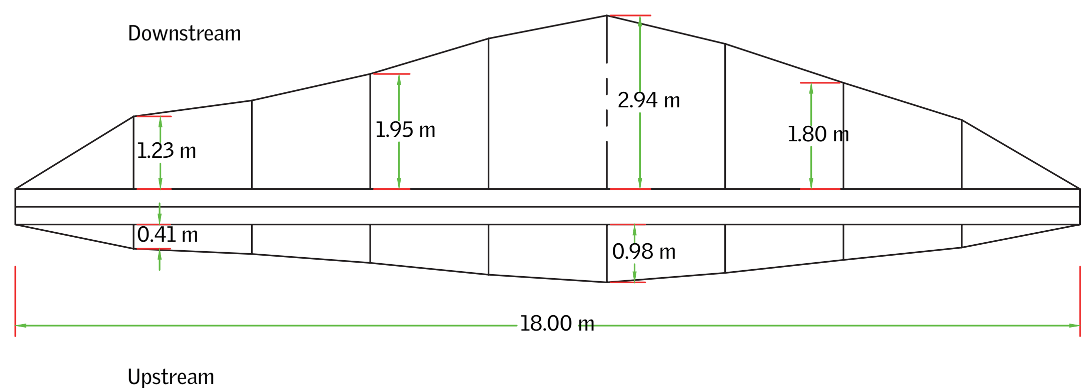
Now, the horizontal interval (HI) is 20 metre and maximum width (MW) of the LBCD is 4.22 metre.

Hence, the effective distance (ED) between two LBCDs	=	HI + MW
	=	**20 + 4.22**
	=	**24.22 metre**
The number of LBCDs in the stream of length 200 metre	=	Length of stream/ED
	=	200/24.22
	=	**8.25 (say 9)**

Therefore, 9 LBCDs can be constructed in a stream of 200 metre with a slope of 5 per cent.

The drawing of the LBCDs is shown in the following figure

Figure 25: Plan/top view of LBCD



Source: Centre for Science and Environment

Figure 26: Front view of LBCD

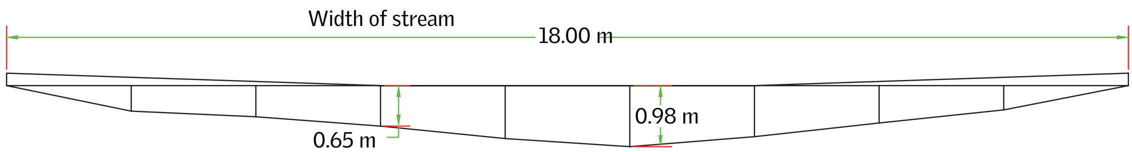
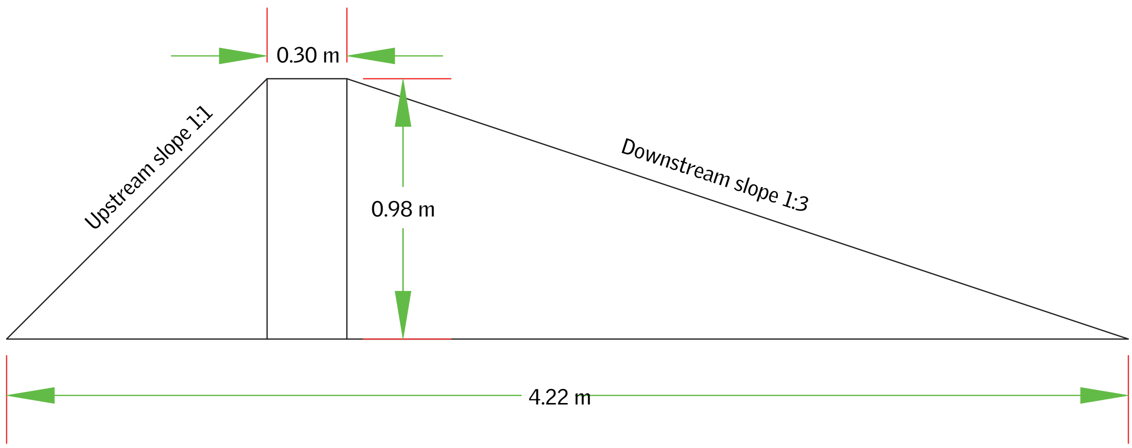
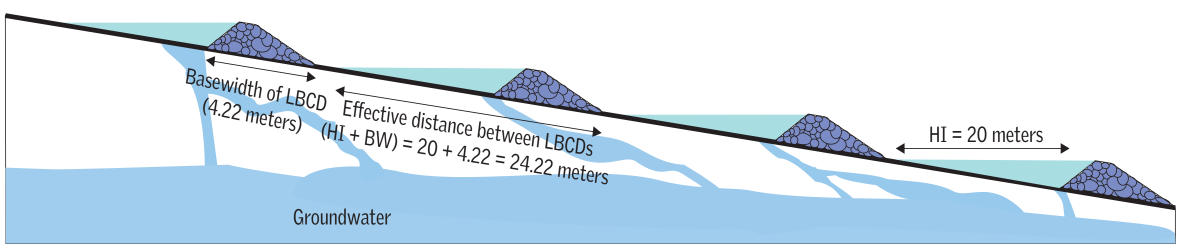


Figure 27: Side view of LBCD



Source: Centre for Science and Environment

Figure 28: Placement of LBCD on slope and its contribution in groundwater recharge



Source: Centre for Science and Environment

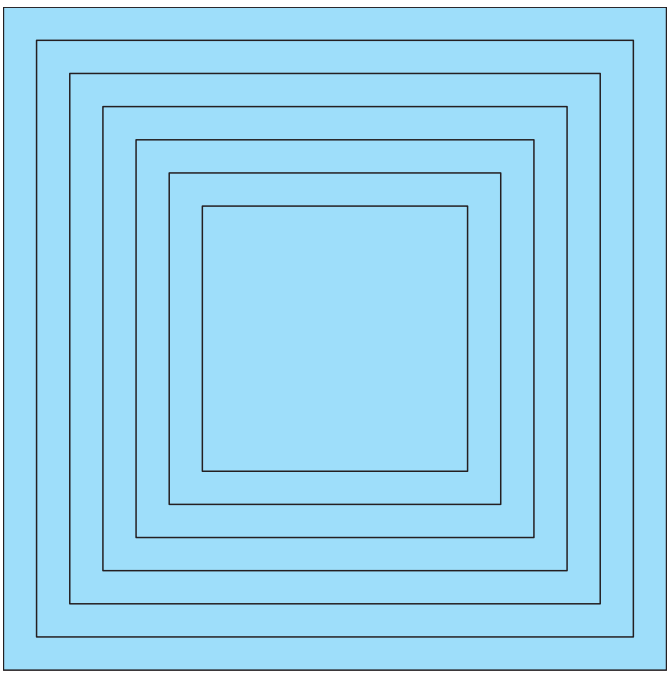
Percolation tank (recharge pond)

A percolation tank is a structure that harvests surface runoff during the rainy season and infiltrates it to the subsurface, where groundwater recharge takes place. It is like a farm pond constructed to irrigate kharif crops, the only difference being that it serves the purpose of groundwater recharge. Ideally the percolation tanks should be constructed on the higher side of the watershed where there are lineaments. The higher side of the watershed forms the catchment of water sources (dug wells, open wells, borewells, handpumps etc.) below. Recharge of the runoff through this percolation tank will augment the water sources below.

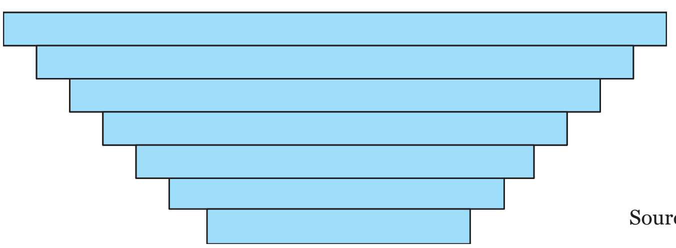
A percolation tank can be a dugout type or an embankment type. Recharge ponds are also called percolation tanks in some states of India.

Dugout percolation tank: Dugout percolation tanks are excavated on the earth in a stepwise manner. A small bund is created in the periphery of the percolation tank so that erosion does not take place. Since the tank is constructed by digging the earth, there is no need for a big embankment around the tank. These tanks are usually constructed in areas where the availability of land is low, and size of the tank is small. The depth of the pond is in the range of 3–4 metre, depending on the depth of the rock below (see *Figure 29: Sectional and plan view of a recharge pond*).

Figure 29: Sectional and plan view of a percolation tank



Plan view (top view) of percolation tank



Sectional view (front view) of percolation tank

Source: Centre for Science and Environment

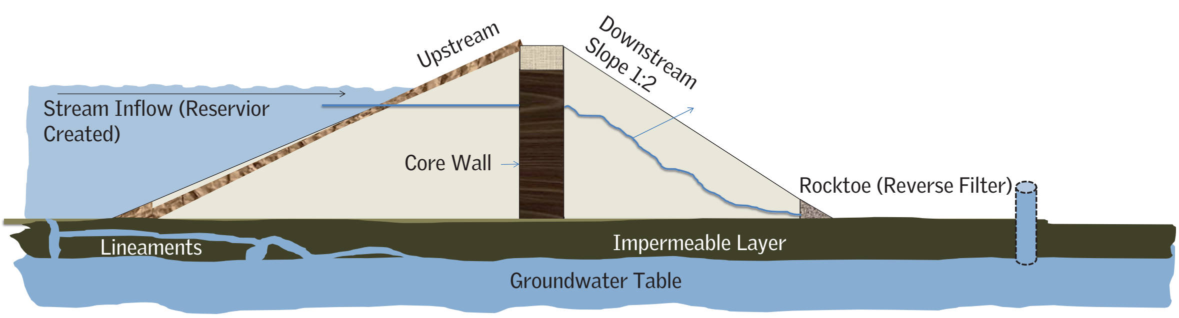
Embankment-type percolation tank: A percolation tank is constructed at a lower elevation than a dugout pond. The slope of the terrain where a percolation tank is constructed is 10–15 per cent. A large embankment is constructed downstream of the site selected for the percolation tank. The embankments of the percolation tanks can be constructed on all four sides. In places where there are second- or third-order streams, embankments in the form of a bund are constructed on one side so that a small pond or percolation tank can be created at that point.

In this case, care should be taken to ensure that there is an impervious layer in the embankment or the bund. The embankments may be created by locally available material. The bund should be made up of locally available materials and the presence of an impervious layer must be ensured within the bund so that no water passes through (see *Figure 30: Typical representation of embankment-type recharge pond or percolation tank*). There may be a seepage which can damage the embankment or bund downstream of the structure. So a rock toe is constructed—with three layers of coarse sand, pebbles and gravels, with coarse sand at the top and gravel at the bottom—downstream of the embankment. Coarse sand should be 0.5–1 mm, pebbles 20 mm and gravel 40 mm in size.

Calculation for storage capacity of percolation tank

To design a recharge pond of any capacity, data of the inflow of water at that location is desirable. The data includes the peak flow, time of concentration, runoff coefficient, details of catchment surface and rainfall details.

Figure 30: Typical representation of embankment-type recharge pond or percolation tank



Source: Centre for Science and Environment

The peak runoff can be calculated as:

RO = A x R x C .... (1)

where,

RO	=	Amount of water collected (runoff) in cubic metre
A	=	Area of catchment
R	=	Average annual rainfall (for 25–30 years)
C	=	Coefficient of runoff

To better understand this concept, let us take an example as follows:

Example

Design a percolation tank with runoff contribution from an area of 58 hectares, and the catchment is forest cover and agricultural fields in the ratio of 3:1. The annual mean rainfall is 825 millimetre, and the mean intensity of rainfall is 25 millimetre per hour.

Now, in this case, the catchment is a mix of forest cover and agricultural field, with coverage of 75 per cent and 25 per cent respectively.

For a catchment, where there are n number of land use land cover, the average coefficient of runoff (Ca) can be used which can be calculated as follows:

$$C_a = \frac{C_1 A_1 + C_2 A_2 + \dots\dots\dots + C_n A_n}{A} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(2)}$$

where,

C_a	=	Average coefficient of runoff
$C_{1 \dots n}$	=	Coefficient of runoff of area 1 to n
$A_{1 \dots n}$	=	Area of different land use land cover
A	=	Total catchment area

So, the Actual Runoff can be calculated as

RO = $A \times R \times C_a$ .... (3)

For this example, the values of all variables are put in the following table:

C1 (forest cover)	A1 (in sq. m)	C2 (agricultural cover)	A2 (in sq. m)	R (in metre)	A (in sq. m)
0.2	435,000	0.25	145,000	0.8	500,000

Putting the values of the variables in equation (2)

$$C_a = \frac{0.2 \times 435{,}000 + 0.25 \times 145{,}000}{500{,}000}$$

$$= 0.2465 \text{ (say 0.25)}$$

We now have the required data, i.e.:

A	=	500,000 square metre
R	=	0.8 metre
C_a	=	0.25

Putting all these values in equation (3)

RO	=	500,000 x 0.8 x 0.25
	=	1, 00,000 cubic metre

Typically, we plan to harvest 60 per cent of runoff, and the remaining 40 per cent is allowed to flow to downstream areas or into streams.

With this example, let us plan to harvest 60 per cent of the runoff, which would be 60,000 cubic metre. So, the capacity of the pond will be the same. It should be kept in mind is that the average annual rainfall (for 25 years) has been taken into consideration.

The actual dimensions of the pond depend on the availability of land at the site and budget available to construct the pond. Let us say that the pond is filled thrice in the rainy season as there are a lot of dry spells due to irregularity of monsoon. The actual capacity of recharge pond will then be the one-third of the harvesting runoff. In this case, the value will be 20,000 cubic metre.

Let us now calculate the size of the percolation tank
The depth of pond is in the range of 3–4 metre, depending upon the soil strata. Let us assume that the depth that we need to make the water percolate down is 4 metre. So, the depth of pond will be 4 metre. We know that volume of the pond is generally a calculation of the volume of a cuboid (in simple terms), which involves multiplying the length, breadth and depth.

Volume (V) = Length (L) x Breadth (B) x Depth (D) .... (4)

$$20{,}000 = \underbrace{\text{Length (L) x Breadth (B)}}_{\textit{Surface area}} \text{ x } 4$$

We know that **Length x Breadth** is the surface area of the pond. So, the calculation can be put in this way:

20,000 = Surface Area x 4

Or,

Surface Area = 20,000/4
Surface Area = 5,000 square metre

So, the Surface Area required for this pond would be 5,000 square metre (or 0.5 hectare or 1.24√(square or rectangle) can be decided.

Let us consider the surface area to be a square here.

Surface Area = 5,000 square metre
= Length (L) x Breadth (B)

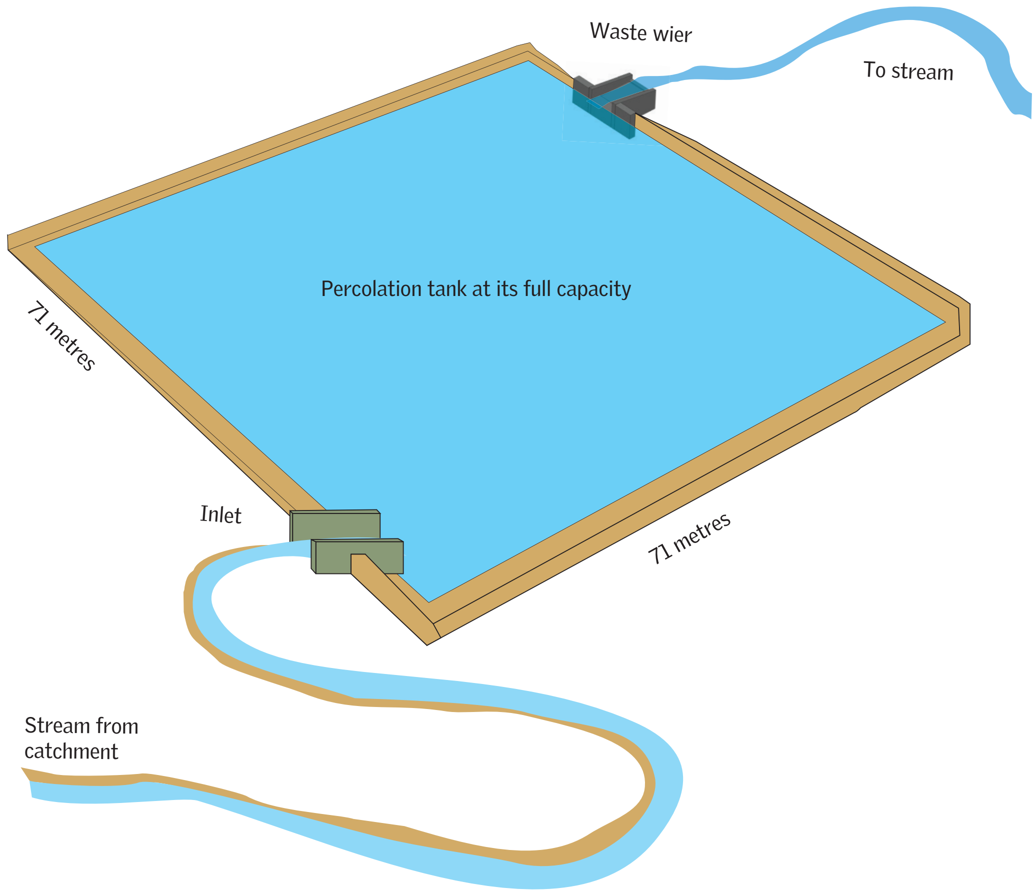
Here L is equal to B, and Hence L x B can be written as L x L = L^2

L^2 = 5,000 square metre
L = √(5000) metre
= 70.7 metre
= 71 metre (rounding off the number)

So, the length and breadth of the pond will be 71 metre each. The final dimensions are:
Length (L) = 71 metre
Breadth (B) = 71 metre
Depth (D) = 4 metre

Since the dimensions have been calculated using all aspects, one thing to be noticed is that the recharge pond will not be constructed as a typical cuboid, but will have a sloping or stepping side surface to prevent erosion and providing a safe way towards its centre. Now, if any of the two options is used, the overall

Figure 31: A representation of percolation tank with inlet and outlet



Source: Centre for Science and Environment

capacity will be reduced. To overcome this issue and construct the percolation tank of required capacity, either the surface area must be increased or the depth, whichever is possible, as per the location of land and its availability for increasing the surface area of the pond.

Calculation of waste weir of pond

A waste weir is a structure constructed for safe disposal of extra runoff arriving in the pond. As discussed, 40 per cent of the total generated runoff is allowed to flow downstream for other users. The same must be made to flow through a waste weir. Various structures for recharge and water harvesting use a waste weir for the safe disposal of extra water.

The discharge through the weir is calculated using a formula which is explained as follows:

Q = A x r x C cumec (cubic metre per second) .... (5)

Where,

Q	=	Peak discharge in cubic metre per second (cumec)
A	=	Catchment area in hectare (ha)
r	=	Intensity of rainfall in mm/hour
C	=	Coefficient of runoff

For the case above, the intensity of rainfall is 25 mm/hour.

To calculate the peak discharge in the above case, the values must be known. These are as follows:

A	=	58 hectare
r	=	25 mm/hr
C	=	0.25

Putting the values in equation (5),

$$Q = \frac{58 \times 25 \times 0.25}{360}$$

= 1.007 cubic metres per second (cumec)

= 1.1 cumec

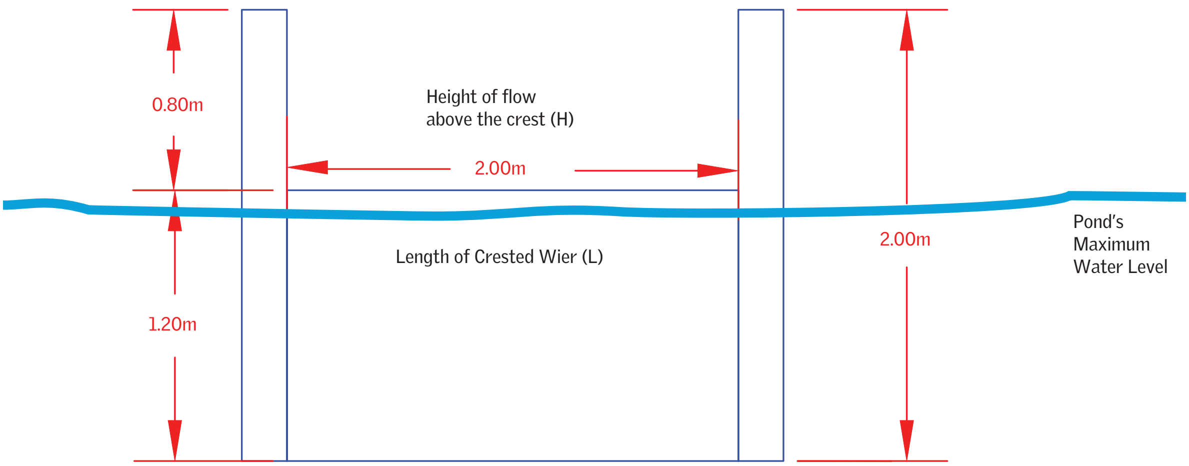
Now, to know the dimensions of waste weir, we use the formula:

Q = $1.6\ LH^{3/2}$ .... (6)

where,

Q	=	Peak discharge in cumec
1.6	=	Constant
L	=	Length of crested weir
H	=	Height of flow above the crest

Figure 32: Calculated dimensions of waste weir



Source: Centre for Science and Environment

Here we have the value of Q which is 1.1 cumec. Also, from the variables L and H, one variable must be decided. So, here we take the value of L as 2 metre.

Putting the values in equation (6),

$$1.1 = 1.6 \times 2 \times H^{3/2}$$

$$H^{3/2} = \frac{1.1}{1.6 \times 2}$$

$$H = \left(\frac{1.1}{1.6 \times 2}\right)^{2/3}$$

$$H = 0.49$$

$$= 0.50 \text{ metre (rounded off)}$$

Thus, the length of the weir will be 2 metre and height of water flow over the crest will be 0.50 metre.

Thus, the structure waste weir can be constructed using the aforementioned details.

Check dams

A check dam is a water-harvesting structure constructed either of stone masonry or from cement concrete on a third or higher order stream. The purpose of a check dam is to check the stream flow and create a reservoir of water which can percolate into the ground augmenting the groundwater sources.

A check dam is constructed in the lower elevation of a watershed, where the slope becomes very gentle, e.g. less than 5 per cent. In rural areas, check dams are a prominent structure to harvest the surface runoff and also used for irrigation.

The selection of a proper site for the construction of a check dam is done on the basis of specific criteria, some of which are the following:
1. The banks of the stream are strong;
2. The slope of the bed of the stream is not more than 5 per cent;
3. The site should be selected at linear stretch of the stream ;
4. For strong foundation of the check dams, hard rock strata should be occurring at a minimum depth below the soil
5. Any site near trees should be avoided; and
6. The site is usually selected near the agricultural lands.

Design of a check dam

A check dam is generally designed on the basis of the following three parameters:
a. Hydrologic design
b. Hydraulic design
c. Structural design

a. Hydrologic design

In the hydrologic design, we need to know parameters like rainfall, coefficient of runoff, soil type, texture and structure of soil, land use land cover and other climatic factors. For designing a check dam at a village or watershed, the average annual rainfall data for a minimum of 20 years is required. The data may be available at the Indian Meteorological Department portal, Krishi Vigyan Kendras, Agricultural Department or any local weather monitoring stations.

To calculate the Peak Discharge (Q) of for a check dam, the catchment area, rainfall intensity and coefficient of runoff is used, which can be put in the following way:

$Q = A \times r \times C$

Where,

Q	=	Peak discharge in cubic metres per second (cumec)
A	=	Catchment area in ha
r	=	Intensity of rainfall in mm/hr
C	=	Coefficient of runoff

b. Hydraulic design

The hydraulic design talks about the calculations of structure's dimensions through which the runoff is disposed of. The crest or headwall of any weir or check dam is designed hydraulically so that the peak runoff can be discharged safely through it, without spilling away the water and causing damage to the nearby areas or structure itself. The correct engineering calculations, thus, becomes vital to ensure safety of the check dam.

The calculations of length of head wall for disposal of peak discharge are given as below:

The length of the head wall of the check dam can be calculates using the "crested weir formula".

According to the crested weir formula,

$$\mathbf{Q = CLH^{3/2}}$$

where,

Q	=	Peak discharge through the weir
C	=	A constant usually taken as 1.77
L	=	Length of the head wall
H	=	Head of flow over the crest

Hence, the length of the head wall can be written as

$$\mathbf{L = Q / CH^{3/2}}$$

c. Structural design

The structural design contains the dimensions of every part of a check dam, including extension wall, wing wall, apron, baffle wall and water cushion etc.

The calculations are required to ensure the stability of the structure through its required weight. The weight of the check dam can only be ensured by providing calculated dimensions to all its parts.

The structural design provides stability to the structure and prevents it from sliding or overturning. In the watershed, since the size of check dams is comparatively small, hydrologic and hydraulic designs are sufficient to estimate the actual design. The other dimensions of the check dam can be designed on the basis of site conditions.

A test pit at least 1.5 metre deep is dug to ensure a hard strata for the foundation of the check dam. It is recommended that the extension wall is a minimum of 1.5–2 metre long, and the apron can be 4–6 metre long. These dimensions are for reference and depend upon actual site conditions. The height of the crest or headwall depends upon the longitudinal survey, and height of water to be stopped in the drainage line.

Once the survey is done, the height of check dam is kept such that the created reservoir does not spill into agricultural fields and submerge any habitat or important land.

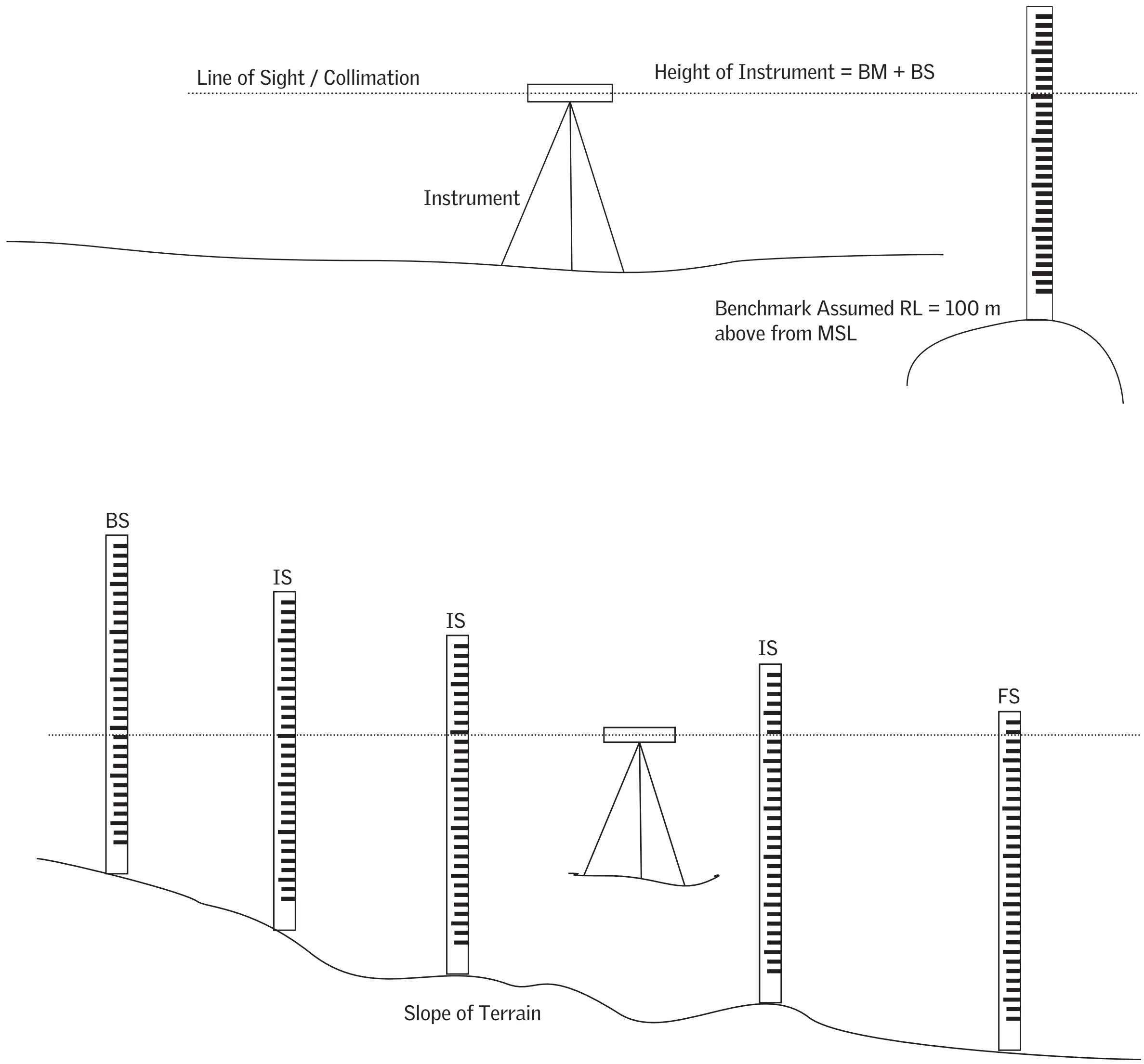
Survey for a check dam

A survey for a check dam is carried out to determine the profile of the drainage and slope of the bed. The actual dimensions of a check dam depend on the longitudinal section and cross section at the site. The survey is conducted by means of surveying instruments such as dumpy level and auto level or modern instruments such as theodolite or total stations.

The objective of carrying out the survey at the check dam site is to find the topography and slope of the terrain bed and the drainage bed. The profile can be mapped using advanced technologies such as GIS and remote sensing data, but for small structures like check dams, the digital elevation model may not provide accurate data. For open source, the pixel size of DEM is 30 metre x 30 metre. A DEM at this scale will not be sufficient to locate the actual terrain profile and drainage slope. Manual survey becomes vital in such situations, and the same has to be carried out using surveying instruments.

The reading of surveying instruments gives the reduced level of the longitudinal and cross-sectional profile of the construction site. Further construction activities will be guided through this reduced level obtained from the survey.

Figure 33: Surveying method using survey instruments



Source: Centre for Science and Environment

Field book

A field book is a small booklet for recording survey data from the field. This data is interpreted to get the profile of the surveyed terrain. The reading from the instrument is recorded in the field book in the form of a table that has various columns (see *Table 25: Field book table to record survey data*).

Left to right: Dumpy level, theodolite, auto level and total station

Table 25: Field book table to record survey data

Station (SN)	Back sight (BS)	Intermediate sight (IS)	Foresight (FS)	Height of instrument (HI) = BS + Benchmark/ RL	Reduced level (RL) = HI – IS/FS	Remark
Note: Unit of measurement is metre						

Drawings of the check dam

Once the design of a check dam is calculated, it is put into the table to find out the dimensions of each section of the dam. A detailed drawing is prepared with three views, namely, front view, side view and top view (plan), to show every part in detail. The views in drawings show the cross sections of a dam at different planes. During the entire calculation process, one unit is used, preferably metre (see *Figures 34: Front and side view of cross section of check dam* and *Figure 35: Front and top view [plan] of check dam*).

Figure 34: Front and side view of cross section of check dam

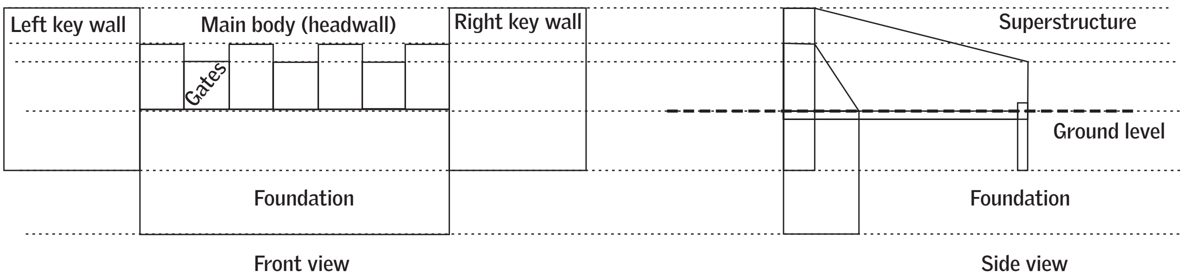
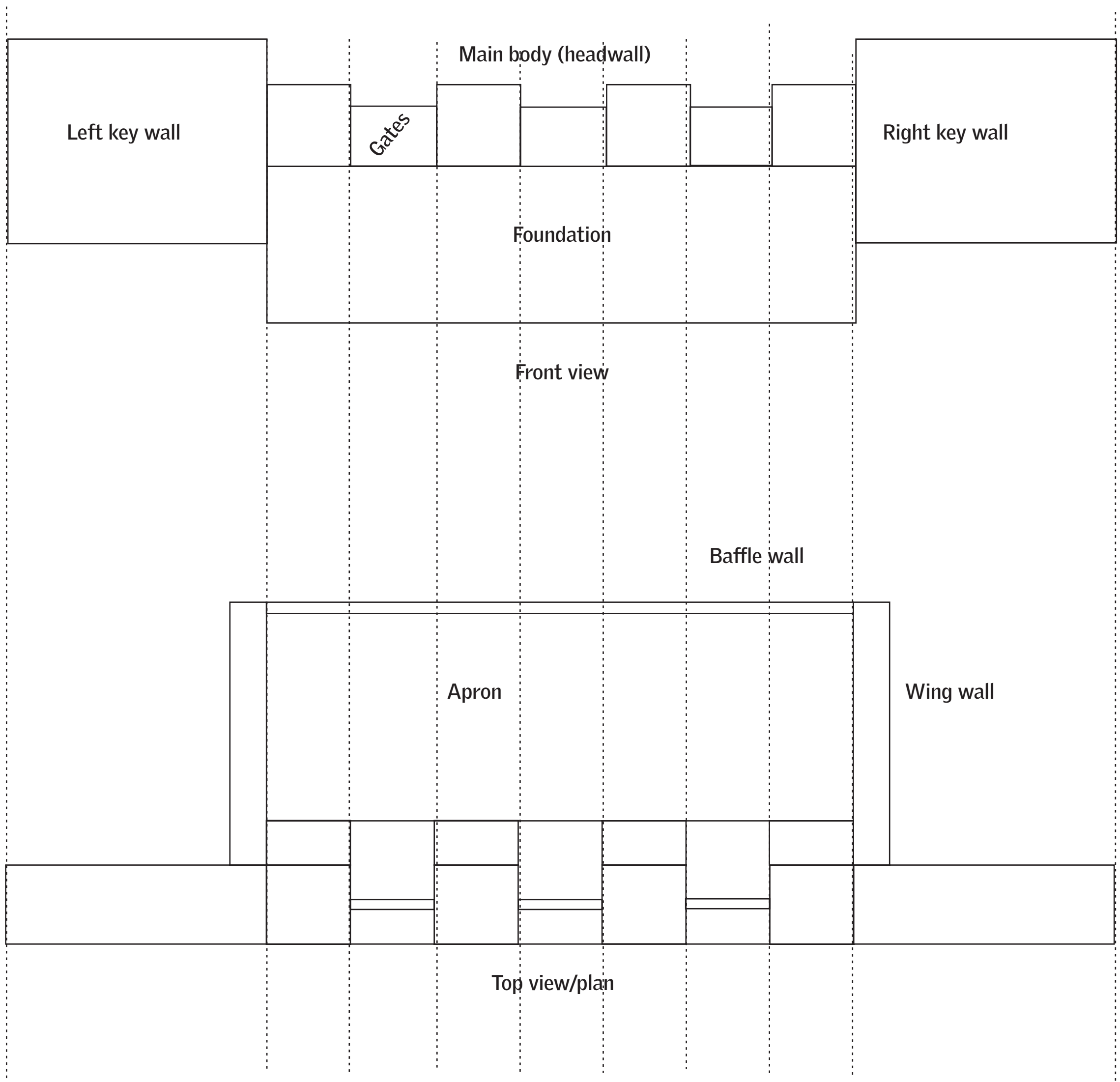


Figure 35: Front and top view (plan) of check dam



Source: Centre for Science and Environment

Estimates for a check dam

The estimate for an engineering structure is based on the overall dimensions and material used for the construction of the structure. In the case of a check dam, the format of estimate is filled with the required dimensions of the structure (see *Table 26: Calculation of bill of quantity (BOQ) for a check dam*).

Table 26: Calculation of bill of quantity (BOQ) for a check dam

Item no.	S. n	Particulars	No.	L	B	H/D	Qty	Unit
302 (a)	1	Excavation for foundation in hard soil with an initial lift of 1.5 metre and a lead of 50 metre, including free dressing.						
		Left key wall						
		Right key wall						
		Head wall						
		Left wing wall						
		Right wing wall						
		Apron						
		Baffle wall						
		Total excavation					0.00	cum
413 (b)	2	Filling of foundation with PCC 1:3:6 with 40 mm metal						
		Left key wall						
		Right key wall						
		Head wall						
		Left wing wall						
		Right wing wall						
		Apron						
		Baffle wall						
		Total PCC					0.00	cum
413 (a) + 416 (a)	3	PCC in 1:2:4 with 20 mm metal for foundation and superstructure						
		Up to ground level						

Item no.	S. n	Particulars	No.	L	B	H/D	Qty	Unit
		Left key wall						
		Right key wall						
		Head wall						
		Left wing wall						
		Right wing wall						
		Apron						
		Baffle wall						
		Total PCC up to ground level (A)					0.00	cum
		Above ground level						
		Left key wall						
		Right key wall						
		Head wall						
		Step 1						
		Step 2						
		Step 3						
		Step 4						
		Step 5						
		Left wing wall						
		Right wing wall						
		Baffle wall						
		Total RRM above GL (B)					0.00	cum
		Total PCC in 1:3:6					0.00	cum
1005 (B)		Plastering 10 mm at the surface of the structure with CM 1:4						
		Left key wall						
		Right key wall						
		Head wall						
		Step 1						
		Step 2						
		Step 3						
		Step 4						
		Step 5						
		Left wing wall						
		Right wing wall						
		Baffle wall						
		Total plastering					0.00	sq m

Table 27: Item-wise cost calculation of a check dam

S. no.	Item no.	Description	Qty	Unit	Rate	Amount
1	302 (a)	Excavation in hard soil				
2	413 (a)	PCC 1:3:6				
3	413 (a) + 416 (a)	PCC 1:2:4				
4	1005 (B)	Plastering (10 mm)				
		Subtotal (A)				

	Transportation of materials						
S. no.	Material	Distance	Unit			Qty	Unit
	Cement		km			0	cum
	Sand		km			0	cum
	Metals		km			0	cum
	Subtotal for transportation cost (B)						
	Total cost (C = A + B)						
	Contingency @ 3.5 % of total cost (D)						
	Labour welfare including shade development, drinking water and first-aid facility (E)						
	Grand total (C + D + E)						

Source: Centre for Science and Environment

While construction of such structures, pressure of the water should be taken into account as any miscalculation at any stage may lead to collapse of the structure.

Other groundwater-recharge structures

Recharge dug well

A dried dugwell can be used as a groundwater recharge structure. Rainwater from surrounding areas can recharge the groundwater through these dug wells.

In the rainy season, such wells fill up, but water is not stored in them for long. Due to the hydraulic gradient created in the well pores or fractures, the water will move downwards or in a lateral direction to meet the water table. Such activity is considered as recharge, which is done through the wells. These wells act as good structures for groundwater recharge, working on the principle of hydraulic conductivity.

Recharge shaft

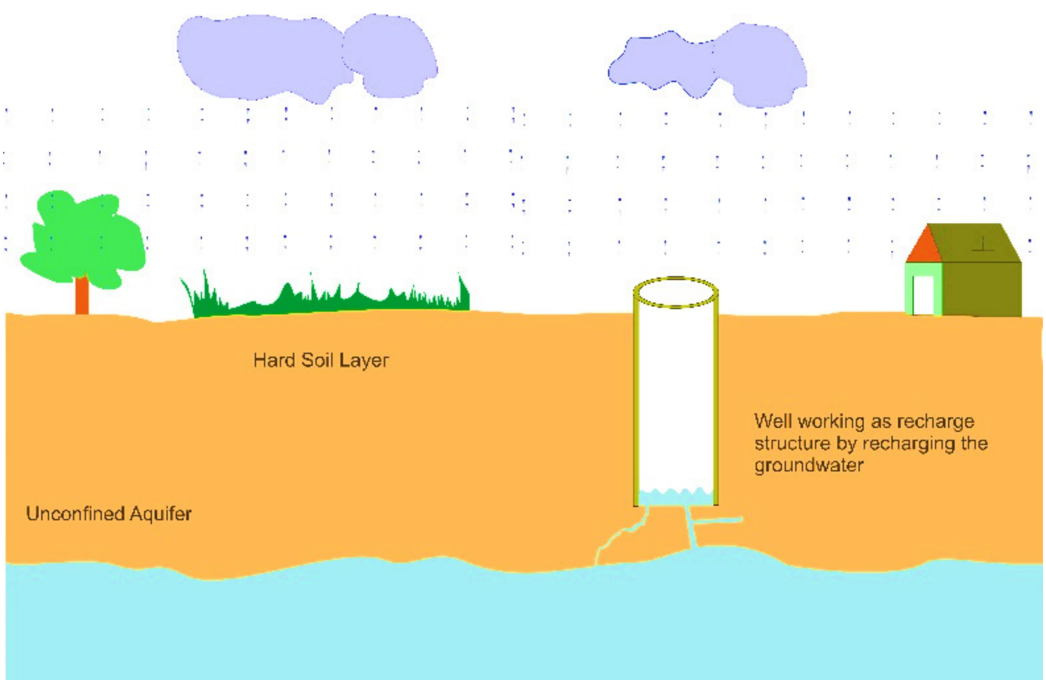
A recharge shaft is a structure constructed to recharge the groundwater directly through the lineaments. As the name signifies, it is a shaft or the borewell-like structure constructed on lineaments, which are identified by means of technologies like GIS or remote sensing or manually mapping the geomorphology of the area. The objective of constructing this structure is to directly recharge the groundwater by collecting rainwater from surrounding areas and diverting into the recharge shafts. These structures are widely used in areas having flat terrain. Even in highly undulating terrains, such structures can play a crucial role in augmenting groundwater.

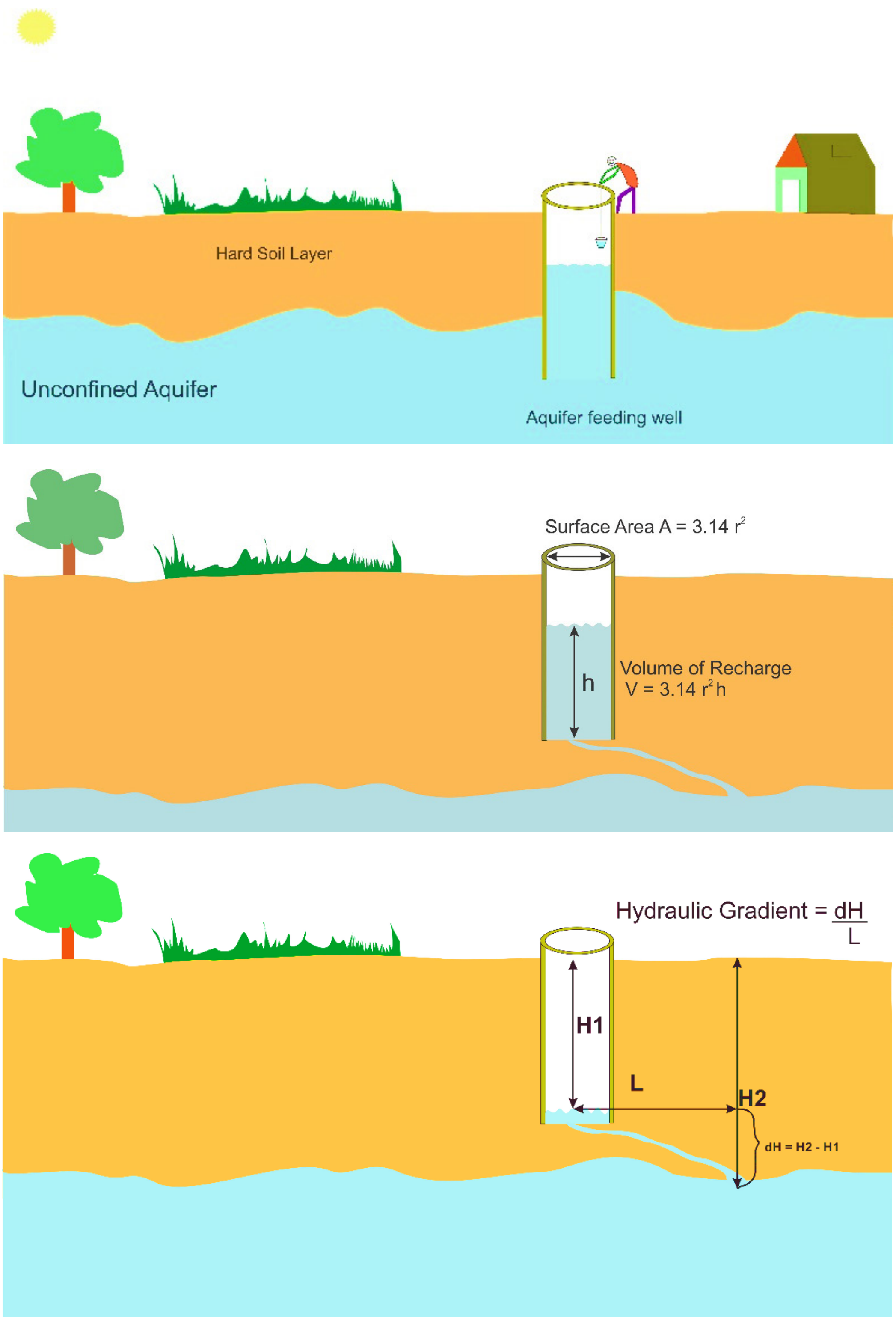
Design

The depth of the borewell/shaft is up to the hard strata beneath the ground. A circular structure around the borewell/shaft is constructed which acts as a container to collect the rainwater, and then discharges into the borewell/shaft, which recharges it to the groundwater through the lineament. The circular section around the borehole can be constructed either of reinforced concrete or brick masonry. A filter material of depth maximum upto 2 metre surrounds the borewell/recharge shaft which helps in filtering the runoff entering the recharge structure. The rainwater is diverted to the auger of the borewell/shaft, which gets accumulated and thus moves to the shaft, which augmentation the groundwater after filtration.

Recharge shaft is one of the most cost-effective and direct artificial recharge methods. It recharges the groundwater faster.

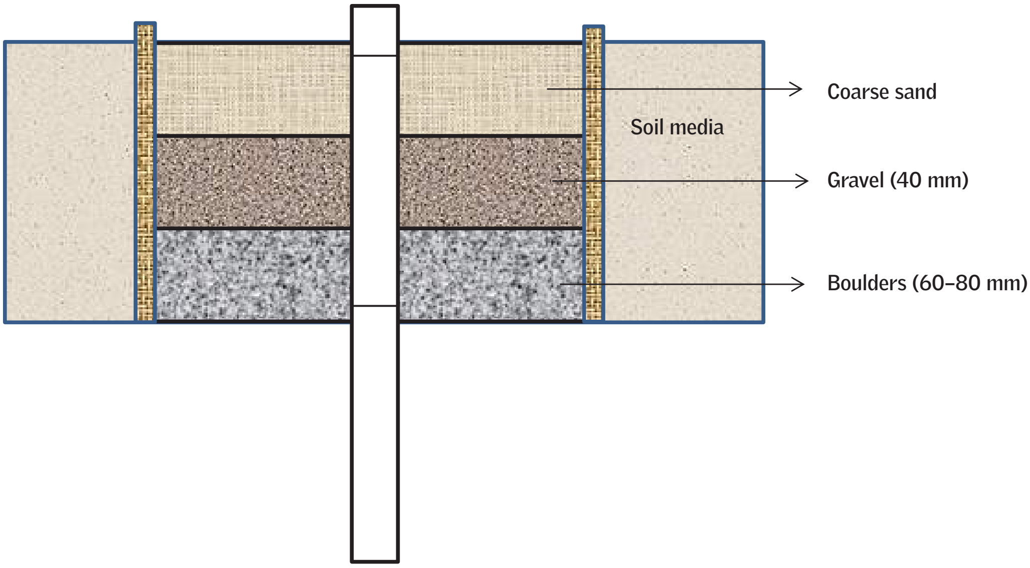
Figure 36: Illustration of dug well recharge

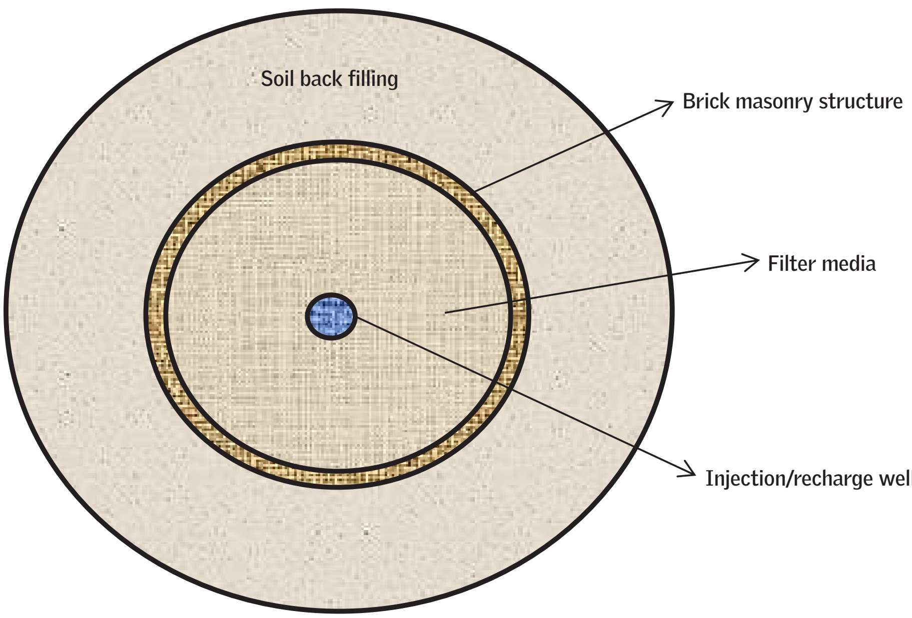




Source: Centre for Science and Environment

Figure 37: Front and top view of a recharge shaft





Source: Centre for Science and Environment

The dimensions and cost estimates of given structures are indicative and would vary depending upon the state, geology, catchment, and year of planning (see *Table 28: Broad estimation of different types of water-harvesting structures in different geological terrains*). The indicative costs have been calculated from the schedule of rates (SOR), Rural Engineering Services (RES), 2019 Madhya Pradesh.

Table 28: Broad estimation of different types of water-harvesting structures in different geological terrains

Type of structure	Size range	Type of rock	Catchment area (in hectare)	Estimated cost range (in Rs)
Loose boulders check dam	3–20 metre	Silt or clay soil, weathered rocks	2–50	5,000–20,000
Earthen gully plugs	3–10 metre	Silt or clay soil	2–20	5,000–20,000
Staggered contour trenches (SCT)	Length: 3–5 metre Width: 1–1.5 metre Depth: 0.6–1 metre	Sandy, loam soil, weathered rocks	5–50	5,000–25,00,000
Water absorption trenches (WAT)	Length: 20–30 metre Width: 1 metre Depth: 1.5 metre	Sandy, loam soil, weathered rock	5–50	20,000–30,000
Percolation tank	0.5–1 acre	Weathered rock	25–100	3,00,000–7,00,000
Farm ponds	Length: 15–20 metre Width: 12–15 metre Depth: 2.5–3 metre	Sandy, loam or clay soil, weathered rock	3–50	1,50,000–3,00,0000
Sunken ponds	Length: 5–10 metre Width: 2–5 metre Depth: 1–1.5 metre	Silt or clay soil	25–100	50,000–80,000
Recharge shafts	Depth: 10–30 metre	Sand, silt, clay, weathered rock	2–25	25,000–1,50,000
Check dam	10–25 metre	Silt or clay soil, weathered rocks	50–1000	7,00,000–30,00,000

Source: Centre for Science and Environment

CASE STUDY

Construction of groundwater recharge structures from ridge to valley of watershed rejuvenated wells in Tikamgarh district, Madhya Pradesh

Issues

Tikamgarh district is a drought-prone area in Bundelkhand. It receives 700–900 mm of annual rainfall. The temperature in summers can be as high as 45–49 degree Celsius. Such intense heat and scanty rainfall makes agriculture difficult. The water scarcity in the region in well-known, as water for agriculture as well as for drinking is scarce.

Shahpur village is situated in Jatara block of Tikamgarh district. It suffered from poor water availability, declining groundwater and loss of vegetation due to loss of in situ moisture. Due of no employment avenues, people from tribal groups and Scheduled Castes migrated to nearby cities in search of work and livelihood. As there were not enough medical facilities at worksites in cities, there was always a risk to the health of children of these families. Decline in agricultural production resulted in loss of income, and drudgery and poverty in the village.

Solutions and impact

To overcome the situation, SRIJAN, a grassroots organization took up the initiative of bringing back water and food security to the village and generating employment. A huge amount of watershed works were implemented under the project Integrated Watershed Management Programme (IWMP). Various structures, including staggered contour trenches (SCTs), farm ponds, field bunding, gabions, boulder checks etc., were constructed following the ridge-to-valley approach of watershed development.

An area of 3.6 hectare under the Forest Department was chosen for construction of the staggered contur trenches, followed by boulder checks and then a farm pond. The trenches were constructed by following all the engineering aspects so that there was no fault. According to the calculations, the dimensions of the trenches were 5 m x 1 m x 1 m (L x B x D). Around 3,000 trenches were constructed, creating a potential recharge of 15,000 cubic metre (15,000,000 litre) in a single fill.

After the construction of staggered contour trenches, there was significant change in the downstream area. Two wells that dried up in December–June every year

Google Earth images pre- and post-watershed intervention

had higher water levels, with water staying longer, after construction of the trenches. The groundwater level in the upper catchment rose by 2–3 metre due to impact of the trenches. The boulder checks also controlled the surface runoff and recharged the groundwater. The wells are now used to irrigate 10 acre of land that was previously left barren due to insufficient water. The owners of wells now cultivate two crops a year, where formerly they cultivated just one. The farm pond downstream also gets subsurface flow of the upper catchment and retains water until January–February every year. It irrigates an additional area of 5 acre where wheat is cultivated in winters. The farmers and their families now don't need to migrate for a livelihood.

Apart from groundwater recharge and irrigation, the works of watershed have also generated employment in the village. In 2015–16, around 1,000 man-days of employment were generated under the Integrated Watershed Management Programme (IWMP), providing income to poor families, especially tribal groups. There is no longer migration to cities in summers for employment as the village offers employment avenues. The creating of water structures has brought back prosperity in the village.

CASE STUDY

Construction of check dam in Chhota Udepur district, Gujarat, recharges the groundwater and has rejuvenated the wells

Chhota Udepur district, in the state of Gujarat, is a semi-arid and drought-prone region characterized by recurring droughts. The average annual rainfall of 952 mm, which largely occurs in June–October, varies in pattern and is unpredictable. The erratic and long dry spells cause severe crop loss. Currently it is estimated that only about 35 per cent of agricultural land has irrigation facilities in the block, hampering the agriculture potential and livelihood of tribal farmers living in the villages of Chhota Udepur block.

Sanada and Chiliyawant village are located in Chhota Udepur taluka of Chhota Udepur district. As per 2011 Census data, Sanada village has a geographical area of 644.78 hectare and a population of 1,842. The geographical area of Chiliyawant village is 717.91 hectare and it has a population of 1,700. The total number of households in Sanada and Chiliyawant village is 316 and 299 respectively.

The major part of these villages comprises hard rock. The only potential zones for groundwater zone is weathered basalt, granite, gneiss etc., covered by soil in the vicinity of rivers and on vast undulating plains adjacent to hilly terrain, but their regional continuity and extent are limited by the heterogeneous nature of deposits with limited thickness. The rainfall in the villages was lost as runoff and there was high dependence on groundwater to meet domestic and agricultural needs. Over the years the groundwater level kept declining until most of the dug wells (shallow wells) become dysfunctional. Water was available in the villages only for four to five months a year. The majority of families have their own land which they cultivate but for most of the year small landholders have no irrigation facilities and migrate to the other part of the state for labour activities.

To overcome the challenges of water management and ensure the availability of water for longer periods of the year, various community-oriented water-conservation and harvesting initiatives were undertaken in both the villages.

The objective of the initiatives were as follows:

- Foster community awareness about land and water resource planning;
- Demonstrate community-oriented water-harvesting techniques;
- Implement land-management techniques to reduce soil erosion and increase moisture retention;
- Augment groundwater recharge to arrest declining water levels.

Several check dams on the stream passing through both Sanada and Chiliyawant had been lying abandoned since 2010–11. Site feasibility was carried out for these structures. They were found to be ideally suited and were taken up for repairing and rejuvenation. Six existing check dams were repaired and nine new check dams were constructed. The construction of these check dam created a total recharge potential of 0.13 million cubic metre of water to the groundwater system.

These check dams are very useful for soil and moisture conservation, water harvesting and recharging groundwater. Recharge through the check dams impacts nearby wells by increasing their water levels, which meets the demand for drinking water. The water stored in the reservoir of the dam is also used for irrigation of crops.

The community was mobilized and sensitized before implementation of the work, and were involved from the inception to the completion of work. A user group comprising five people was formed to look after the operation and maintenance of these structures. This benefitted a population of 525 and approximately 90 acre of land.

PHOTO CREDIT: FARAZ AHMAD

Check dam in village Chiliyawant, Chhota Udepur district, Gujarat

"There was no proper facility for water in the village before 2018–19. Out of 12 months, water was available only for eight months. We could grow only one crop in the entire year. The rest of the year we worked as labour. Now, since the construction of check dams, the situation has changed. We have ample water through the year. I grow three to four crops a year such as maize, wheat, black gram and urad."

—Bhursinghbhai Lattubhai Rathwa, beneficiary, resident of Chiliyawant village, Chhota Udepur district

Chapter 6: Monitoring the impact of groundwater recharge systems

- Monitoring is important to understand the impact of groundwater recharge.
- Monitoring should be periodic or continuous, depending on the use of groundwater.

We have dso far detailed the designing of groundwater recharge structures and locating them in suitable areas for effective groundwater recharge. This chapter will deal on monitoring the effect of groundwater recharge. The impact on the groundwater can be both qualitative and quantitative.

Generally, at the country level, the Central Ground Water Board, Ministry of Jal Shakti, is responsible for monitoring groundwater levels as well as quality of groundwater. But the Central Pollution Control Board (CPCB), as per their mandate, monitors groundwater quality. Groundwater boards at the state level also have a network of observation wells for monitoring levels of groundwater as well as quality. Both shallow and deeper aquifers are monitored through observation wells which may be open wells or piezometers. Open wells can give the data on shallow aquifers, but piezometers can be planned in such a way that it can record groundwater-level data in one or more aquifers.

As per the government definition, a piezometer is a borewell or tube well used only for measuring the water level by lowering the tape/sounder or automatic water-level-measuring equipment. It is also used to take water samples for testing water quality whenever needed.

Monitoring of groundwater level

The objective of water-level monitoring is to study the impact of recharge on groundwater reserves through various structures. The groundwater should be monitored judiciously at strategic points so that the impact of groundwater recharge at specific area can be observed. Monitoring of groundwater levels should be planned at very beginning of any groundwater recharge project.

The following are the two types of monitoring:

a. Periodic monitoring
b. Continuous monitoring

Periodic monitoring

- Periodic groundwater-level measurements are made at scheduled intervals (i.e. daily, weekly, fortnight, monthly or seasonally).
- Periodic water-level measurements are usually carried out through manually or digitally through sensor-based piezometers.
- The most popular periodic monitoring is done during pre-monsoon, monsoon and post-monsoon periods.

Continuous monitoring

- Continuous monitoring is near real-time monitoring.
- This type of monitoring is suitable for areas that face regular fluctuations of groundwater levels or there is a substantial change in groundwater quality within a short span of time.

After planning for the implementations to be undertaken for groundwater recharge management is complete, it is important to identify and/or locate monitoring wells for monitoring water levels (before implementation). The wells identified can be existing wells near the planned structure and can be marked and given a code/serial. The same wells should be monitored over years for a particular site for groundwater recharge.

While identifying wells for monitoring of impact, a few things should be taken into consideration:

- Wells should be in close vicinity to the planned structure.
- The well should not be for the purpose of extraction as due to pumping, the water elevation in the well may not represent the actual piezometer elevation. If such a well is used, care should be taken to ensure that pumping is stopped at least 24 hours before monitoring.
- The monitoring well must be well maintained.
- The well should be easily accessible even in the monsoon period so that water-level readings can be easily taken.

Guidelines for installation of piezometers and their monitoring as per Central Groundwater Board of India (CGWB)

- The piezometer is to be installed/constructed at a minimum distance of 50 m from the pumping well through which groundwater is being withdrawn.
- The measurement of water level in piezometer should be taken only after pumping from the surrounding tube wells has stopped for about four to six hours.
- The frequency of measurement should be monthly, and the accuracy of the measurement is very important. The reported measurement should corrected to two digits after the decimal.

The installation involves several operations. Depending upon the drilling technique and the nature of the strata, some of these operations may be sequential while others may be overlapping. The operations may be classified as follows:

- Drilling of the borehole (including preparation of well log/determination of the depth and thickness of the aquifer to be monitored);
- Lowering of the borewell assembly
- Gravel packing/sealing;
- Final borewell development

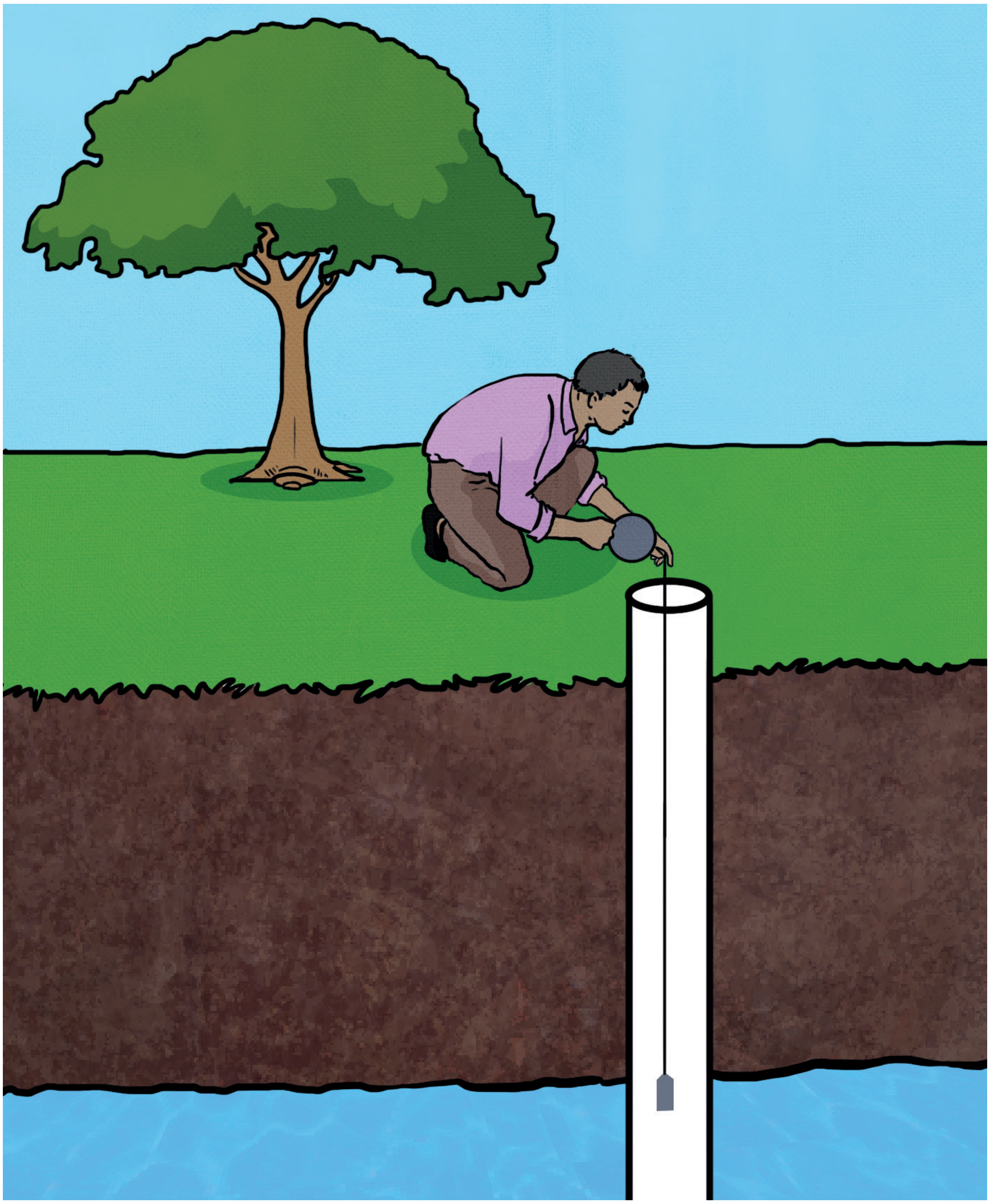
How to measure water level: There are two methods to measure water level (see *Figure 38: Measuring water level in an observation well*).

Conventional method

- Steel tape can be considered the oldest yet the most accurate technique of measuring the water levels. Steel tape is lowered into the borewell, by mounting it with a weight. The lower end of the tape should have a chalk mark. The weight should ensure that the tape goes straight into the well. Then, the tape is pulled up to the surface before the chalk mark dries. The submerged portion of the tape is then measured and adjusted in the final reading of the tape.

- Steel tape has been developed into electronic measuring tapes or tape sounders, which are made up of a pair of separated insulated wires. Well dippers and sounding devices with acoustic and light signs are practical and extensively used to check groundwater levels more accurately and quickly. Sounding devices work by reeling the tape down the well with care while avoiding the casing's sides. When the system sounds, the reading of the depth to water is measured with care. The probe is raised and lowered in and out of the water to obtain a consistent outcome.

Figure 38: Measuring water level in an observation well



Source: Centre for Science and Environment

Digital and advanced method

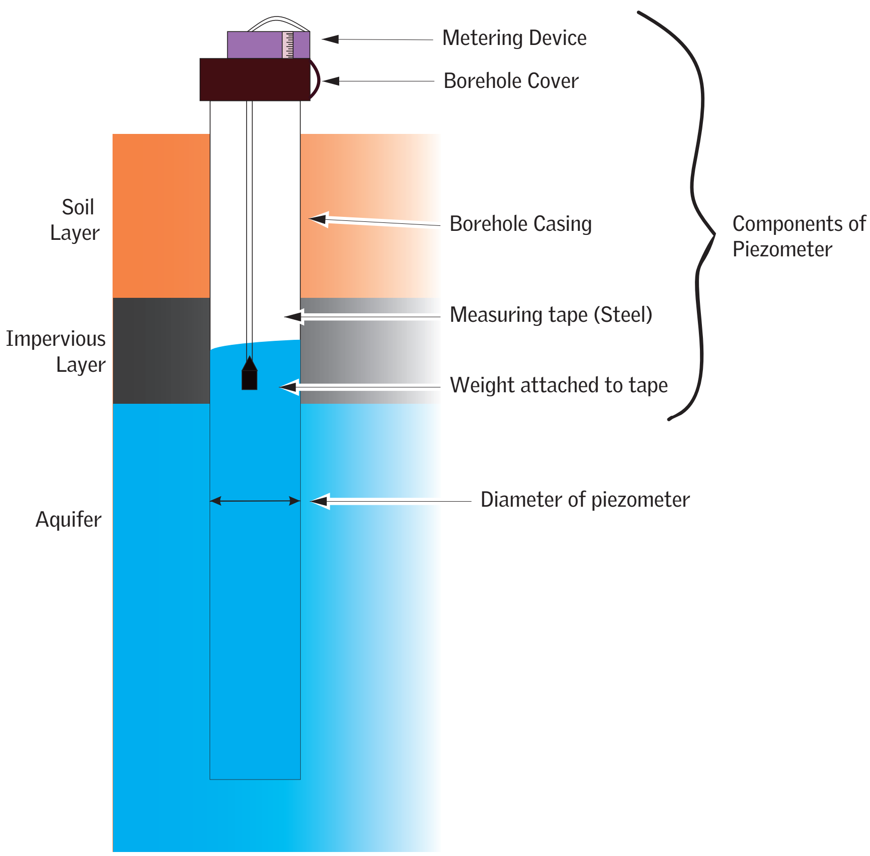
Continuous monitoring or near-continuous monitoring is usually carried out using digital water-level recorders (DWLR), which are programmed to make measurements at specified frequencies. DWLRs are mounted in several piezometers to help in better understanding of the groundwater recharge system and recharge in various hydrogeological conditions (see *Figure 41: Different parameters of impact measurement*).

The digital method provides the most accurate estimate of maximum and minimum water-level fluctuations in aquifers where the hydraulic response of an aquifer to stresses is slow and the frequency and magnitude of water-level changes in an observation well are also low.

Interpreting water-level data

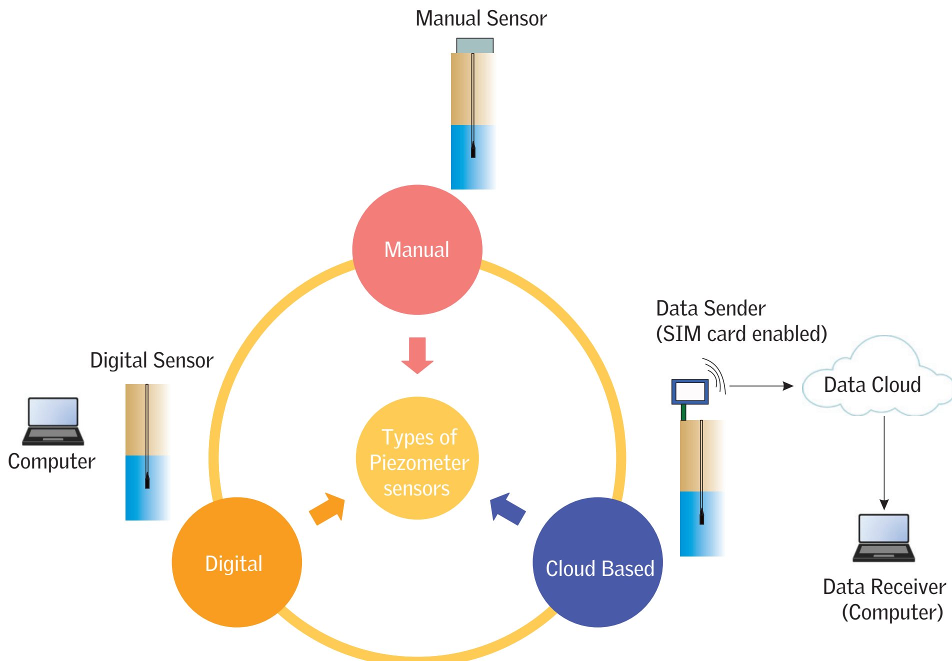
The acquisition and interpretation of water-level data are essential parts of any environmental site characterization or groundwater monitoring programme. A quick and easy method to interpret groundwater measurements is to plot the data against time. This type of figure is known as a hydrograph. After several measurements have been taken, the water levels in the well(s) can be compared to

Figure 39: Components of a piezometer



Source: Centre for Science and Environment

Figure 40: Types of piezometer sensors



Source: Centre for Science and Environment

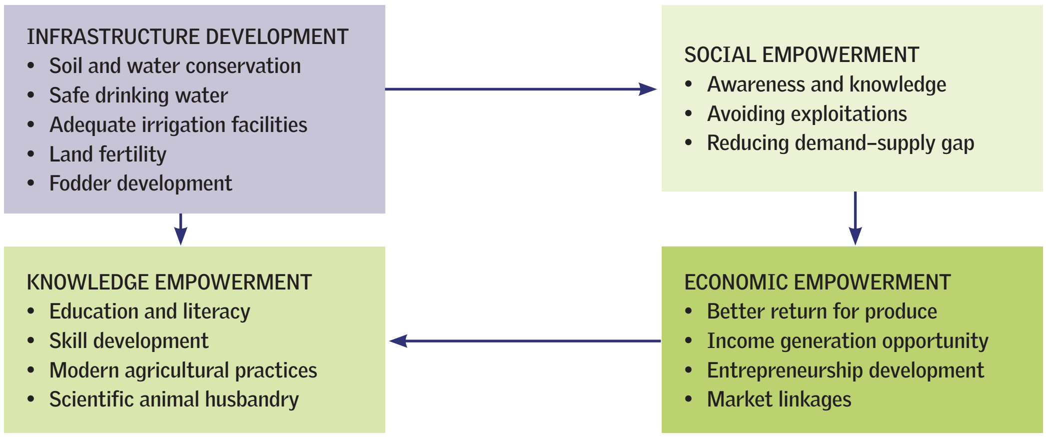
see if there are any decline or rise or seasonal and/or drought responses (see *Graph 8: Hydrograph showing the trend of water level on the piezometer in Akshardham Temple in East Delhi monitored by CGWB*). After planning and implementation of water-harvesting measures, it is important to measure the impact that has resulted due to the interventions.

The purpose of an impact assessment is to determine the welfare changes from a given intervention on individuals, households and community levels. Impact assessments are often undertaken by evaluating the impact of past, current and future interventions.

An impact assessment will help to answer the following questions:
Will interventions improve the water levels?
Will it increase the water availability in the existing borewell/well?
Will it reduce the waterlogging?
Will it improve water quality?
Who will benefit?

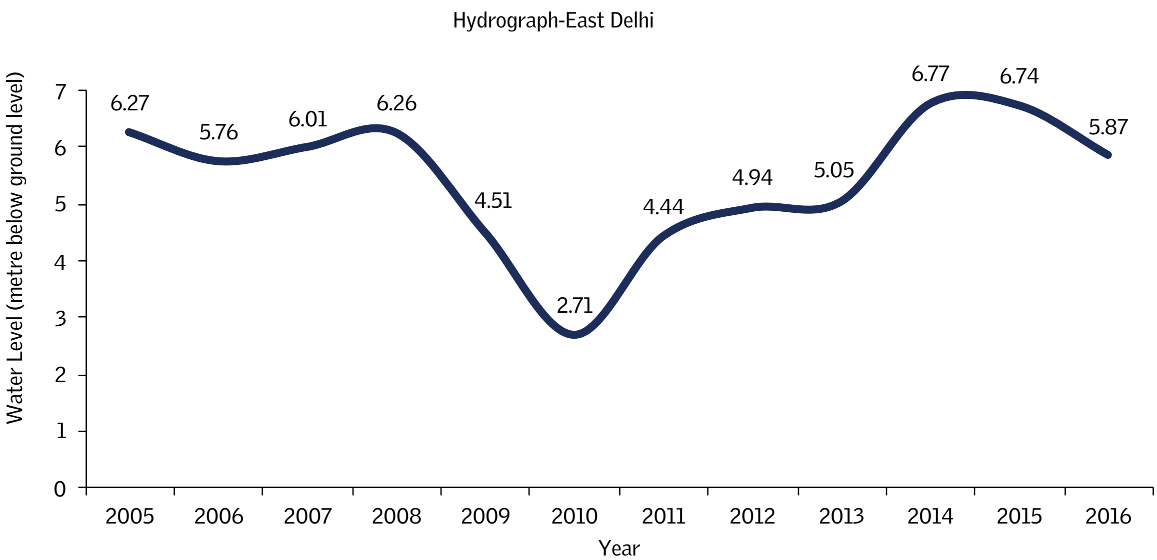
The impacts can be measured or identified on the basis of various parameters such as infrastructural development, social, knowledge and economic empowerment (see *Figure 41: Different parameters of impacts measurement*). Keeping in view

Figure 41: Different parameters of impact measurement



Source: Compiled by CSE

Graph 8: Hydrograph showing trend of water level on the piezometer in Akshardham Temple in East Delhi monitored by CGWB



Source: Compiled from CGWB data

these parameters of assessment, various indicators need to be monitored and assessed in order to understand the impact of water-management solutions (see *Table 29: Indicators for monitoring groundwater-management interventions*).

Table 29: Indicators for monitoring groundwater-management interventions

S. no.	Indicators	Questions that need to be answered
1	Assured water for domestic and agricultural use	What was the situation before the initiatives? Has the demand–supply gap of water availabile and water utilized reduced? Do farmers get water throughout the year for their crops?
2	Safe and assured drinking water	Is water available 24 x 7 post initiatives? Have health issues in the community declined? Do women and girls need to spend any time in fetching water? Has the hygiene of women and girls improved?
3	Reduced soil degradation	Is there erosion of soil with runoff?
4	Improved groundwater levels	Has there been a rise in water level, improved quality of water, improved yield of wells and water availability in lean months?
5	Improved soil moisture	Has the irrigation cycle for crops reduced where there is enhanced soil moisture?
6	Water conservation	Is there longer availability of water in streams, canals, and other surface waterbodies? Is there adequate infrastructure to hold rainfall and avoid runoff?
7	Occurrences of floods and drought	Has the number of incidents of flood or drought (depending on the issue in area) fallen?
8	Area of land under irrigation	How much barren land has been brought under irrigation?
9	Cropping intensity	Has the cropping pattern improved (mono-cropping to multi-cropping) and scope of crop diversity and/or yield of crop improved?
10	Increase in income of farmers	What is the percentage of increase in income of farmers per unit of land?
11	Migration	Has the number of migrating population reduced?
12	Cattle and livestock population	Is there any increase in cattle and livestock population? Is there assured fodder and water availability for them?
13	Entrepreneurship	Have market linkages improved, incomes in local businesses increased, innovations in farming techniques increased, and cultivation of cash crops increased?
14	Attendance in school and higher education	Has attendance of students, especially of girls, improved in schools? Has the percentage of students going for higher education increased?
15	Improved livelihood	Are living conditions better? Is there an increase in number of bikes, cars, television, fridge, pukka houses, bank accounts and saving etc.?

Monitoring of groundwater quality

The government also monitors the quality of groundwater across years. The quality parameters generally checked for groundwater are TDS, chloride, fluoride, iron, arsenic and nitrate etc. The Central Groundwater Board only talks about parameters that are natually occuring. Pre-monsoon, monsoon and post-monsoon groundwater monitoring have to be done to understand the impact of groundwater recharge in a specific area. The qiuality of groundwater, however, can be impacted by anthropogenic effects (e.g. nitrates in groundwater due to leakage of septic tanks).

References

Chapter 1: Introduction

1. https://cgwb.gov.in/GW-Assessment/GWRA-2017-National-Compilation.pdf
2. The United Nations Millennium Declaration, signed in September 2000, commits world leaders to combat poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. The MDGs are derived from this Declaration. Each MDG has targets set for 2015 and indicators to monitor progress from 1990 levels. Several of these relate directly to health.
3. WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene, 2020.
4. state-of-drinking-water-report_ex-summary_english.pdf (who.int) (as viewed on February 3, 2023).
5. Unit-level data and report on NSS 76th Round for Schedule 1.2, July–December 2018 (Drinking Water, Sanitation, Hygiene and Housing Condition), Ministry of Statistics and Programme Implementation, Government of India (mospi.gov.in) (as viewed on January 11, 2023).
6. https://www.unicef.org/india/what-we-do/clean-drinking-water (as viewed on February 2, 2023).
7. Global Water Security and Sanitation Partnership (GWSP) (worldbank.org) (as viewed on February 2, 2023).
8. *India Groundwater: A Valuable but Diminishing Resource* (worldbank.org) (as viewed on February 5, 2023).
9. Ibid.
10. https://www.unicef.org/india/what-we-do/clean-drinking-water (as viewed on February 5, 2023).
11. https://cag.gov.in/uploads/performance_activity_report/PerformanceActivityReport-05f10796ce979d6-66136828.pdf
12. Jal Jeevan Mission Dashboard (https://ejalshakti.gov.in/jjmreport/JJMIndia.aspx) (as viewed on November 24, 2022).
13. Sushmita Sengupta and Swati Bhatia 2022, *Big Change is Possible: Best Practices in Water Supply and Sanitation in India*, Centre for Science and Environment, New Delhi.

Chapter 2: Step-by-step planning for augmentation of groundwater resources

1. National Compilation on Dynamic Groundwater Resources of India, 2020, Central Ground Water Board, Ministry of Jal Shakti, Government of India.
2. Manual on Artificial Recharge of Groundwater, September 2007, Central Groundwater Board, Department of Water Resources, Ministry of Jal Shakti
3. Ibid.

Chapter 3: Locating potential zones for groundwater recharge using advanced tools

1. Bhuvan is a portal of the National Remote Sensing Centre (NRSC), which contains different thematic maps of India. (www.bhuvan.nrsc.gov.in).
2. https://cgwb.gov.in/District_Profile/Rajasthan/Barmer.pdf

Chapter 4: Developing a decision matrix

1. Manual of Artificial Recharge of Groundwater Sources, September 2007, Central Groundwater Board, Ministry of Water Resources, Government of India.
2. Bhuvan is a portal of the National Remote Sensing Centre (NRSC), which contains different thematic maps of India. (www.bhuvan.nrsc.gov.in).
3. The Integrated Watershed Management Programme (IWMP) is a Centrally sponsored scheme. Previously it provided funds to the states in the ratio of 90:10 (where one-tenth was the share of the state). The ratio is currently 60:40. The aim of this programme is to restore ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water.

Over 60 per cent of India's population—who lives in rural India—depends heavily on groundwater, extracted though handpumps, borewells and wells, as their source of drinking water.

India has launched programmes around drinking-water supply to rural areas six times post-Independence. Each of the programmes failed to meet the goal of total coverage of households. Due to drying of sources, many villages slipped from total coverage to partial coverage and even no coverage. Sustainability of the sources—both for quality and quantity—had never been central to the programmes until the recent Jal Jeevan Mission (JJM).

This toolkit presents options for recharging underground water sources through different technologies. It details the planning and designing of groundwater-recharge structures to specific hydrogeological conditions and application of advanced tools for planning the correct structure at the appropriate location. It also showcases success stories where these structures were used while giving the context of the technologies. It emphasizes the importance of community engagement for the sustainability of groundwater recharge structures.

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