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Water Conservation and Artificial Recharge of Aquifers in India

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ABSTRACT

India has proud traditions and wisdom which have evolved over thousands of years for developing technologies for water conservation and groundwater recharge using surplus monsoon precipitation runoff. This is imperative as the average rainfall/precipitation period is about 27 days/year and with uneven distribution across the country. Groundwater development is now the mainstay for sustaining agricultural production and rural water supplies. As such, groundwater development is increasing at an exponential rate and the estimated draft is now 231 000 hm^3 with the result that almost 15% of the groundwater development areas are showing a continuous decline of water levels. There is an anomalous situation whereby water levels are declining in 831 blocks (assessment units) out of a total of 5 723 blocks across the country, and availability of excessive 864 000 hm^3 runoff in different river basins brings floods and creates water logging in some parts of the country. This non-utilizable water can be planned for creating small surface water storage and to create additional sub-surface storage through groundwater recharge. At present, total water available is estimated at 660 000 hm^3 and the minimum estimated water demand will be 843 000 hm^3 in 2025 and 973 000 hm^3 in 2050. Therefore, if India wants sustainable food supplies and to meet domestic/industrial water requirements, there is no other option than to implement projects for water conservation/groundwater recharge. Although a number of forward looking steps have been planned by the government and other institutions, many lacunae have been observed which need to be addressed for the successful implementation of water conservation and recharge programmes. This paper discusses various practices from the pre-historic to the present day, with case studies showing technological intervention.

Key words: artificial recharge, food sustainability, over-exploitation, run-off, water conservation.

Conservación de agua y recarga artificial de acuíferos en India

RESUMEN

India tiene tradiciones y sabiduría desarrolladas durante miles de años para el desarrollo de tecnologías para conservación de agua y recarga artificial de acuíferos utilizando excedentes procedentes de las lluvias monzónicas. Esto se ha convertido en una necesidad, ya que la relación de días de lluvias por cada años es de 27 días, con el problema añadido de la distribución irregular a lo largo de todo el país. La explotación del agua subterránea es ahora el principal recurso para mantener la producción agrícola y el abastecimiento de agua rural. Dicha explotación está aumentando a un ritmo exponencial, y la cantidad extraída actualmente se estima en 231000 hm^3/año, y casi el 15% de las áreas de explotación están sufriendo una continua disminución de los niveles del agua subterránea. No es una situación anómala, por lo que los niveles de agua están disminuyendo en 831 bloques (así se denominan las Unidades de Evaluación en India) de un total de total de 5723 bloques en el país. Existe un total de 864000 hm^3/año de recursos excedentarios procedentes de la precipitación en diferentes cuencas, que originan inundaciones en algunas partes del país. Esta agua no utilizable se puede planificar para la creación de pequeños depósitos de agua superficial y crear almacenamientos sub-superficiales adicionales a través de la recarga de acuíferos. En la actualidad, el total de agua disponible se estima en 660000 hm^3/año, mientras que la demanda de agua prevista es de 843000 hm^3/año para 2025 y 973000 hm^3/año para 2050. Por lo tanto, si la India pretende mantener la seguridad alimentaria y satisfacer las necesidades de agua doméstica / industrial, no hay otra opción que la ejecución de proyectos para la conservación y recarga de acuíferos. Aunque se han dado ya algunos pasos por parte del gobierno y otras instituciones, hay todavía muchas lagunas que se han detectado y que necesitan ser cubiertas para la implementación con éxito del programa de recarga y conservación del agua. Este artículo analiza diversas prácticas de recarga artificial a partir del período prehistórico hasta la fecha, mostrando el papel de la tecnología en el desarrollo de esta técnica en India.

Palabras clave: Escorrentía, conservación de agua, recarga artificial, seguridad alimentaria, sobreexplotación.

ABRIDGED VERSION IN SPANISH

Introducción

Los actuales problemas que existen para satisfacer la demanda actual y prevista con los recursos hídricos disponibles en India ha llevado a la conclusión que que es necesario utilizar escorrentías excedentarias procedentes de las lluvias monzónicas como un elemento más de la gestión hídrica. Más del 50 % de la precipitación anual se produce en un tiempo de alrededor de 15 días y en menos de 100 horas. Bajo este escenario, se prevé incrementar la capacidad de almacenamiento del país hasta 384000 hm^3 en el año 2050. Por otra parte, la explotación de los recursos hídricos subterráneos se estima en 433000 hm^3/año, lo que ha provocado un descenso de niveles en casi el 20% de bloques o unidades de gestión de agua del país, y, en muchas zonas costeras, intrusión marina. El Plan Nacional de Aguas Subterráneas contempla el desarrollo de la recarga artificial y de proyectos de conservación y ahorro como elementos de gestión hídrica.

El objetivo del presente artículo es dar a conocer las diferentes tecnologías desarrolladas en las proyectos puestos en marcha en India para la conservación y el ahorro de agua y los de recarga artificial de acuíferos.

Perspectiva histórica de la recarga artificial en India

Históricamente, la India ha estado poniendo en práctica actuaciones para la conservación y ahorro del agua, y para presevar su calidad en los últimos siglos. Los primeros vestigios históricos datan del siglo I AC, en donde se utilizaban pozos de ladrillo para la extracción de agua. Posteriormente, desde el Siglo I hasta el Siglo III, se empezaron a construir represas para regadío. Durante el Siglo VIII, se construyeron estructuras nuevas para la recarga de las aguas subterráneas. Una de ellas es la que se muestra en la figura 1, pozos con escaleras en su interior, conocidos como baolis, que se utilizaron desde el siglo IX hasta el XVII. Son estructuras que sirven tanto para la conservación de las aguas subterráneas como para el uso lúdico, ya que todos tienen habitaciones.

Durante el siglo XII, se contruyeron en zonas áridas estructuras cilíndricas subterráneas, conocidas con Tankas (figura 2), de profundidades variables y cuyo objetivo era el almacenamiento de agua. Los Tankas eran típicos de la zona desértica, donde no se genera escorrentía superficial debido a la presencia de dunas de arena.

Ya en tiempos modernos, puede decirse que los primeros proyectos piloto de recarga artificial de acuíferos se puesieron en marcha durante el período 1972-1984, en asociación con el Pprograma de las Naciones Unidas para el Desarrollo, utilizando diversas técnicas:

1. *Recarga inducida en la aldea de Tatiana, distrito de Kurukshetra, Haryana en la margen izquierda del río Ghaggar*
2. *Inyección en Dabkheri, distrito de Kurukshetra, Haryana*
3. *Diques subsuperficiales en el Estado Seed Farm, Ananganadi, Kerala*
4. *Pozos de inyección en el distrito de Kamliwara Mehsana, Gujarat*
5. *Balsas de recarga superficiales en Mehsana, Gujarat*

Entre los períodos 1984-1992 hubo un parón, que terminó durante el período de 1992 a 1997, en donde el Gobierno comenzó a financiar experiencias con el fin de demostrar la viabilidad de esta tecnología. Este programa continuó durante el periodo 1997-2007, y se ha viso fortalecido durante el periodo en curso 2007-2012.

En 1996, se preparó el Plan Nacional de Perspectiva (National Perspective Plan), a la vista de un período corto de monzón con grandes excedentes de escorrentía superficial disponibles, y de la posibilidad de llenar de agua la zona no saturada mediante recarga artificial, de tal manera que la profundidad del nivel del agua se elevase hasta 3 metros por debajo del nivel del suelo. La escorrentía disponible para la recarga se cifró en 872000 hm^3/año, mientras que el potencial de almacenamiento en la zona no saturada se calculó en 590000 hm^3/año. Este plan fue seguido de un Plan Maestro para la recarga artificial de aguas subterráneas en la India. Los proyectos piloto se han comenzado a construir en zonas residenciales de mandatarios, lugares religiosos y en lugares importantes con objeto de demostrar a la población las bondades de la tecnología.

Proyectos piloto construidos en India

1. En sedimentos aluviales

A. Estado: Delhi

a) Recolección de agua lluvia en tejados, Sharam Shakti Bhawan

Esta experiencia tiene como finalidad la utilización de la escorrentía generada en las azoteas de los edificios de la zona del campus universitario y en sus zonas pavimentadas. Se construyeron 3 zanjas de recarga, cada una con 2 pozos de inyección (Figura 5).

b) Estructuras de recarga en el metro de Delhi

Se planea la construcción de estructuras de recarga para utilizar escorrentías procedentes de los monzones en las secciones de metro elevadas (Figura 6).

c) Plan de Recarga Artificial en el Aeropuerto Internacional Indira Gandhi, Nueva Delhi

Se trata de aprovechar escorrentías del monzón a través de la construcción de los drenajes de aguas pluviales y una estructura de recarga en el desagüe, constituida por 20 pozos de recarga (Figura 7).

B. Estado: Punjab

Se trata de un proyecto para corregir el descenso del nivel freático, como consecuencia de la explotación del agua subterránea, mediante la transformación de un dren de 30.8 km de longitud en una instalación de recarga artificial, que constará de 30 zanjas con filtros y 30 pozos de inyección.

2 . En acuíferos constituidos por basaltos

A. Estado: Maharashtra

Se pretende utilizar la técnica del "water harvesting" en zonas en las cuales se desarrolla una agricultura de alto rendimiento, y en la cual, el descenso provocado en los niveles freáticos alcanza los 40 m. La estructura de recarga artificial propuesta consta de 2 tanques de percolación y 5 pozos de recarga, para rellenar un volumen subterráneo libre potencial de 153 hm^3 (Figura 9).

3. También se ha propuesto alguna experiencia piloto en acuíferos constituidos por granitos, en el estado de Karnataka, mediante diques.

4. En zonas costeras afectadas por intrusión marina, como por ejemplo, en el estado de Orissa, se ha propuesto utilizar el agua dulce de varios cauces para inyectarla en las zonas salinizadas para reducir el contenido en sal del agua subterránea, de manera que la misma sea útil para riego y otros fines.

5. Diques subsuperficiales en el estado de Kerala

En Kerala, las condiciones del terreno dificultan la retención subterránea del agua, por lo cual, se ha puesto en marcha una experiencia piloto que consiste en construir diques subsuperficiales para la gestión del caudal de base con objeto de inducir almacenamiento subterráneo mediante recarga artificial.

6. Otros esquemas de recarga artificial puestos en marcha son:

- *(i) pozos excavados*
- *(ii) reparación, renovación y restauración de las balsas de almacenamiento de agua en pequeños pueblos.*
- *(iii) recarga mediante canales*
- *(iv) estructuras para la conservación y ahorro de agua en las islas de Andaman y Nicobar, mediante la construcción de diques.*

Iniciativas y medidas para el ahorro y la recarga artificial de acuíferos puestas en marcha en India

A. Medidas en las que interviene el Gobierno

1. *Creación en 2006del Consejo Asesor de Recarga Artificial de Acuíferos, del Ministerio de Recursos Hídricos del Gobierno de la India. Sus miembros proceden tanto del Gobierno como de ONG y otras partes interesadas .*
2. *El Parlamento constituyó en 2005un Forum Parlamentario dedicado a la conservación y gestión del agua.*
3. *El Ministerio de Recursos Hídricos ha instituido el Premio Nacional del Agua en el año 2007 sobre proyectos relacionados con el ahorro del agua.*
4. *Se ha hecho obligatorio disponer de un sistema de recogida de aguas pluviales en todas las casas con una superficie de más de 100 m^2 y en todas las parcelas con una superficie de más de 1000 m^2.*

B. Limitaciones

1. *La construcción de presas.*
2. *La calidad del agua.*
3. *En la actualidad no existe una base de datos que contenga el número y los diferentes tipos de instalaciones de recarga artificial o ahorro de agua en todo el país. Por lo tanto, es difícil cuantificar la cantidad de agua que se recarga artificialmente en los acuíferos. Sería de gran interés disponer de esa base de datos nacional.*
4. *Tampoco existe una institución central o del Estado que proporcione criterios técnicos para el diseño de las estructuras de recarga y supervise su funcionamiento. Además, el seguimiento posterior de los proyectos terminados no es obligatorio.*
5. *La propiedad de agua recargada o ahorrada.*

Introduction

The inadequacy of water resources to meet the present and future demand has led to plan the utilization of non-committed monsoon runoff as the best management tool. The average annual rainfall is 1170 mm but it varies from 100 mm in western Rajasthan (mostly desert area) to about 11000 mm in the north-eastern Himalayan region. More than 50% of the precipitation takes place in about 15 days and less than 100 hours altogether in a year. Under this scenario, the surface water storage in different river basins is only 214000 hm^3 compared to the planned storage of 690000 hm^3. It is now projected that the surface storage through major and medium dams will increase to 384000 hm^3 by 2050. Because additional surface water storage will not be available in the near future due to environment questions, settlement of displaced persons and other issues, dependence on the development of groundwater resources is increasing still further. The annual replenishment of (dynamic) groundwater resources is estimated at 433000 hm^3, out of which 231,000 hm^3 have already been developed, resulting in a decline of water levels in 831 blocks (assessment units) out of total 5723 blocks; this has caused saline groundwater intrusion in many places in the inland and coastal areas, deteriorating water quality. The projected future minimum demands for water resources are 843000 hm^3 compared to the available 660000 hm^3, which has made it imperative to plan and utilize excessive monsoon runoff. For this purpose the National Groundwater Perspective Plan and the Master Plan have been developed in critical areas for the systematic implementation of water conservation and recharge projects. Although a number of projects have been completed using different techniques there is still no database available at national level. The runoff potential available in different river basins and the feasibility for recharge is given in Table 1. In most of the river basins significant non-utilized runoff potential during the monsoon period is available for groundwater recharge but three of the river basins have a deficit in water resources to meet the estimated water requirements.

Objective

The increasing demand for water resources is due to many reasons, making it imperative to explore management options to supplement the existing water resources to meet the existing water demand and to also take into account the climate change scenario. India has taken the initiative to implement MAR projects as a measure to mitigate the demand and as an adaptation measure. The aim of this paper is to show the various technologies developed in areas for water conservation and recharge.

Study area

The study area covers the Indian sub-continent, where water conservation and artificial recharge projects using different methods and techniques are being used with improved technologies for supplementing the available water resources, both surface water and groundwater.

Historical Perspective

Historically, India had been practicing water conservation for many centuries and this has been well documented in Vedic literature. To protect the water conservation structures from any form of pollution, the construction of the structures was associated with various religious, cultural and social rituals to keep them pure and clean. In the first century B.C. brick and ring wells were designed for the extraction of water; in the 1st to 3rd centuries A.D. lake and

S.No.	Basin	Available Water for recharge	Subsurface storage potential For Recharge	Feasible Ground-Water Storage	Retrievable groundwater storage	Water availability To meet Requirement of Groundwater Storages	
1	2	3	4	5	6	Excess	Deficit
1.	Indus	31236	143813	31236	21665	--	112577
2.	(D) ganga (E) brahmaputra (F) barak & Others	238126 307752 No storage Potential	125076 19177	125076 19177	94930 15883	113050 288575	-- --
3.	Godavari	53124	8145	8145	5818	44979	--
4.	Krishna	17835	8970	8970	6407	8865	--
5.	Cauvery	8132	4746	4746	3406	3386	--
6.	Pennar	2742	1940	1940	1386	802	--
7.	East flowing rivers krishna-pennar & manahanadi-godavari	8562	832	832	594	7730	--
8.	East flowing rivers pennar-kanyakumari	10882	5731	5731	4145	5151	--
9.	Mahanadi	26187	2055	2055	1468	24132	--
10.	Brahmani & baitarni	14603	483	483	345	14120	--
11.	Subarna-rekha	4406	868	868	630	3538	--
12.	Sabarmati*	1489	8134	1489	1116	--	6645
13.	Mahi	4587	1883	1883	1345	2704	--
14.	West flowing rivres of kutch & kakthiawar including luni*	5814	150181	5814	4371	--	144367
15.	Narmada	10244	77356	10244	7687	--	67112
16.	Tapi	3830	4448	3830	2752	--	618
17.	West flowing rivers of Tapi to tadri	65612	907	907	648	64705	--
18.	West flowing rivers of tadri to kanya kumari	49537	518	518	370	49019	--
19.	Areas of inland Drainage in rajasthan*	Nil	25310	Nil	Nil	--	25130
	Total	864700	590573	233943	174963	630126	356629

* Deficit basins
Notice: MCM (1000 MCM = 1 BCM)

Table 1. Annual water resources available in various river basins for water conservation/recharge.
Tabla 1. *Recursos hídricos anuales en diferentes cuencas disponibles para proyectos de conservación o recarga.*

well irrigation techniques were developed and large dams were constructed across major rivers in the south. In the 11th and 12th centuries A.D., major revolutions took place and one of the main existing lakes in Bhopal was constructed in an area of 647 km^2. The development of various structures for water management from the 3rd century B.C. to 18th century is briefly given in Table 2.

3rd millennium B.C.	Dams built of stone rubble were found in Baluchistan and Kutch.
3000 – 1500 B.C.	Indus - Sarasvati Civilization had several reservoirs to collect rainwater runoff. Each house had an individual well.
3rd Century B.C.	Kautilya's Arthasastra mentions irrigation using water harvesting systems.
1st Century B.C.	Sringaverapura near Allahabad had a sophisticated water harvesting system using the floodwaters of the Ganges.
2nd Century A.D.	Grand Anicut or Kallanai built by Karikala Chola across the river Cauvery to divert water for irrigation is still functional.
11th Century A.D.	King Bhoja of Bhopal built the largest artificial lake (65,000 acres) in India fed by streams and springs.
12th -18th Century A.D.	Rajatarangini by Kalhana describes a well- maintained irrigation system in Kashmir, Tankas, Step wells.

Such local water conservation practices were discont

Table 2. Traditional water harvesting practices in India.
Tabla 2. *Prácticas de "water harvesting" en India a lo largo del tiempo.*

The understanding of the occurrence and disposition of the aquifer system became better known in the 8th Century and many new structures were constructed for the development and recharge of groundwater. One of the technological developments was the design and construction of *baolis* or step wells, mostly in the arid and semi-arid areas of north and west India between the 9th to 17th centuries, before pumping to withdraw groundwater was invented. In the *baolis*, the steps were constructed above the occurrence of the water table and the whole structure was architecturally design and decorated with paintings. The paved areas of the *baolis* act as catchment areas to create enough runoff which is then diverted to the step well. Associated with the step well was the deep, open well protected from pollution for storage water. These structures served as groundwater conservation and development, recreation and resting places, as all these *Baolis* have a number of rooms (Figure 1). Some of the *Baolis* are still functional and in use. These are well designed ethnic structures showing high competency in architectural design and technology.

Another important technological evolution was during the 12th century when the *tankas,* a cylindrical underground structure with variable depths, were constructed in arid areas for water storage. The *tankas* were typical of the desert area where runoff is not created due to the sand dunes; therefore the artificial

Figure 1. *Baolis* or step wells for groundwater recharge and development.
Figura 1. *Pozo con escaleras en Baolis para recarga artificial.*

Figure 2. A *tanka* or underground storage cement structure with an artificial catchment area, a 10th century structure.
Figura 2. *Estructura para almacenamiento subterráneo cementada de Tanka, con un área vertiente artificial. Siglo X.*

catchment area was created by constructing a large diameter cement structure around the *tankas*. In the areas where these technologies were developed, the groundwater is saline so no other such structure could serve the purpose. These structures are still being constructed in desert areas and also in semi-arid areas where the groundwater is saline (Figure 2).

Water Conservation and Groundwater Recharge

The sources of water in India had so far been the rainfall, and other sources of water of good quality were not used either for conserving water or recharging groundwater. Groundwater development was being accelerated and in few places water levels were declining and this gave rise to the initiation of groundwater recharge using different methods. The initial pilot projects were initiated during the period 1972 to 1984 in association with the United Nations Development Programme (UNDP) using the following techniques:

1. Induced recharge in Tatiana village, Kurukshetra district, Haryana on the left bank of the Ghaggar River.
2. Injection method in Dabkheri, Narwana branch canal, Kurukshetra district, Haryana.
3. Sub-surface dike at the State Seed Farm, Ananganadi, Kerala.
4. Injection well at Kamliwara Mehsana Distt, Gujarat.
5. Spreading channels at Mehsana, Gujarat.

From 1984 to 1992 there had been no efforts towards rainwater harvesting programmes or groundwater recharge. It was only during the period 1992-97 when the government fully financed a pilot project to demonstrate the technology for different types of recharge structures. The programme was further continued during the period 1997-2002, and 2002-2007, and further strengthened during the ongoing period 2007-2012.

National Perspective Plan

In 1996, the National Perspective Plan was prepared in view of the following circumstances: firstly, a short monsoon period, secondly, availability of excessive runoff in different basins and thirdly the hydrogeological situation and the possibility to saturate the vadose zone, for the depth to the water level to rise to 3 metres below ground level. The plan presented a conceptual framework for the utilization of surplus monsoon runoff for conservation and artificial recharge of groundwater. The features of the National Perspective plan are given below:

- Non-committed surplus monsoon runoff available for recharge: 872000 hm^3.
- Sub-surface storage potential (saturating the vadose zone up to 3 metres below ground level): 590000 hm^3.
- Of the 590000 hm^3, retrievable storage potential: 437000 hm^3.
- Feasible ground water storage on the basis of availability of monsoon runoff and storage potential of the vadose zone: 214000 hm^3.
- Utilizable storage potential out of 214000 hm^3: 161000 hm^3.

This prospective plan was followed by a Master Plan for the artificial recharge of groundwater in India by considering the availability of non-committed potential. The features are given below:

- Area Identified for artificial recharge: 448760 km^2
- Volume of water to be recharged: 36453 hm^3
- Total number of structures proposed: 3925000
- In urban areas (roof-top rainwater harvesting) : 37000000
- In rural areas : 225000
- Check dams /cement plugs/*anicuts* = 1.10000
- Recharge shafts, dug wells = 48000
- Gully plugs /Gabbion structures = 26000
- Development of springs = 2700
- Revival of ponds/tanks = 1000

The types of water conservation or artificial recharge projects implemented from 1992 to 2002 are given in a pie diagram (Figure 3) showing the type of the water conservation and groundwater recharge structures constructed.

These pilot projects have been constructed in the residential areas of the president of India, heads of states, political leaders and religious sites and at important locations to show people friendly, low-cost technology for medium to big dams and also for the awareness and dissemination of knowledge. The location of important structures

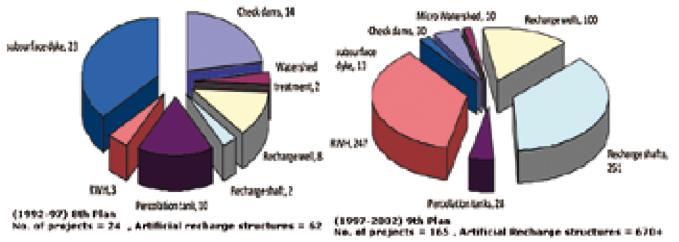


Figure 3. Pie diagram showing the number and type of recharge structure under different pilot projects from 1992 to 2002.
Figura 3. *Número y tipo de instalaciones de recarga realizadas en diferentes proyectos piloto en el período 1992-2002.*

is given in Figure 4 which shows the construction of these structures in different geological formations, the hydrogeological conditions and the rainfall patterns etc. The benefits accrued out of the construction of these pilot projects have been very significant.

Some of the pilot projects constructed are briefly described below:

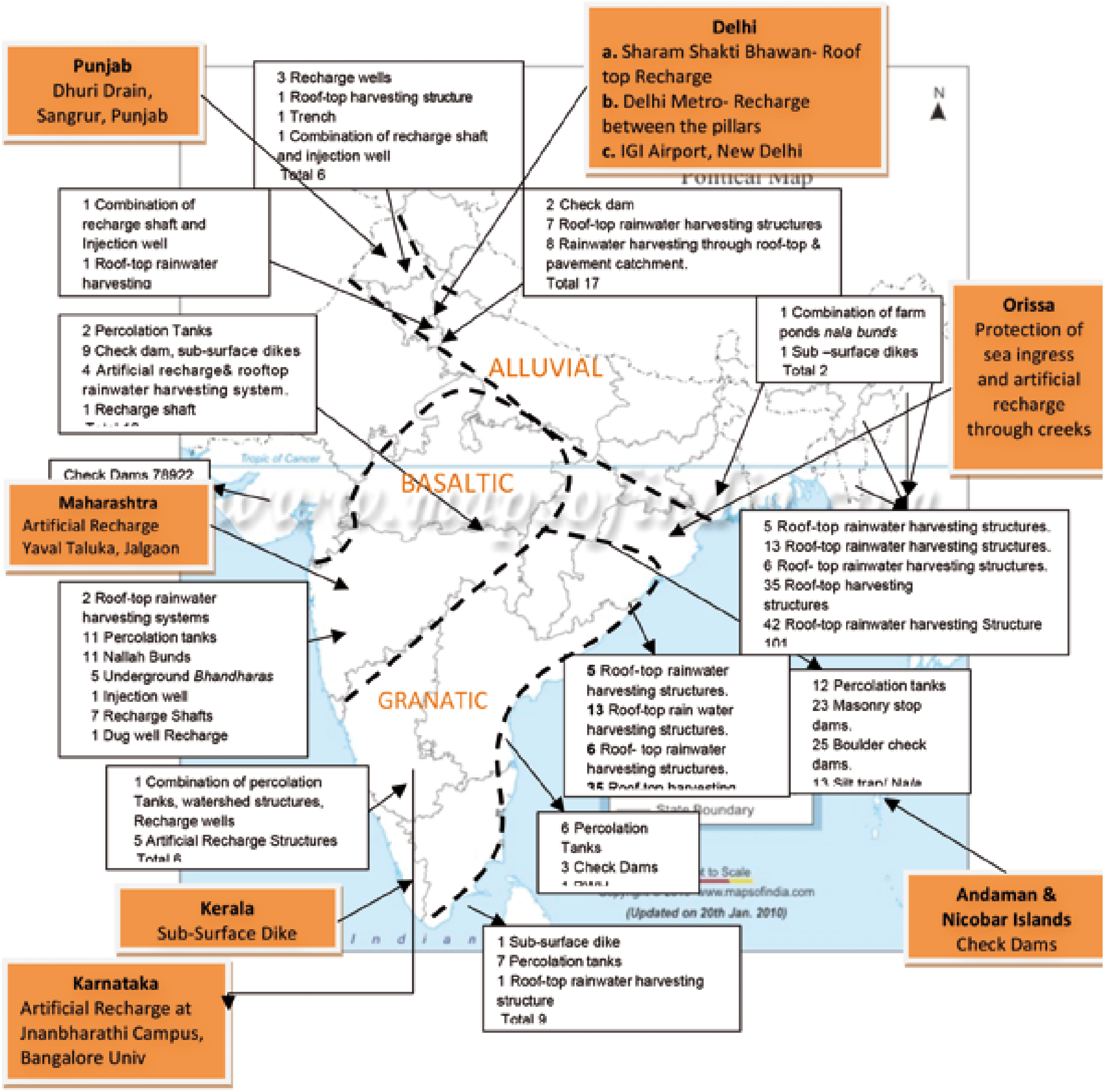


Figure 4. Map showing the location and types of pilot-project structures constructed across India.
Figura 4. *Localización y tipo de instalaciones piloto de recarga a lo largo de India.*

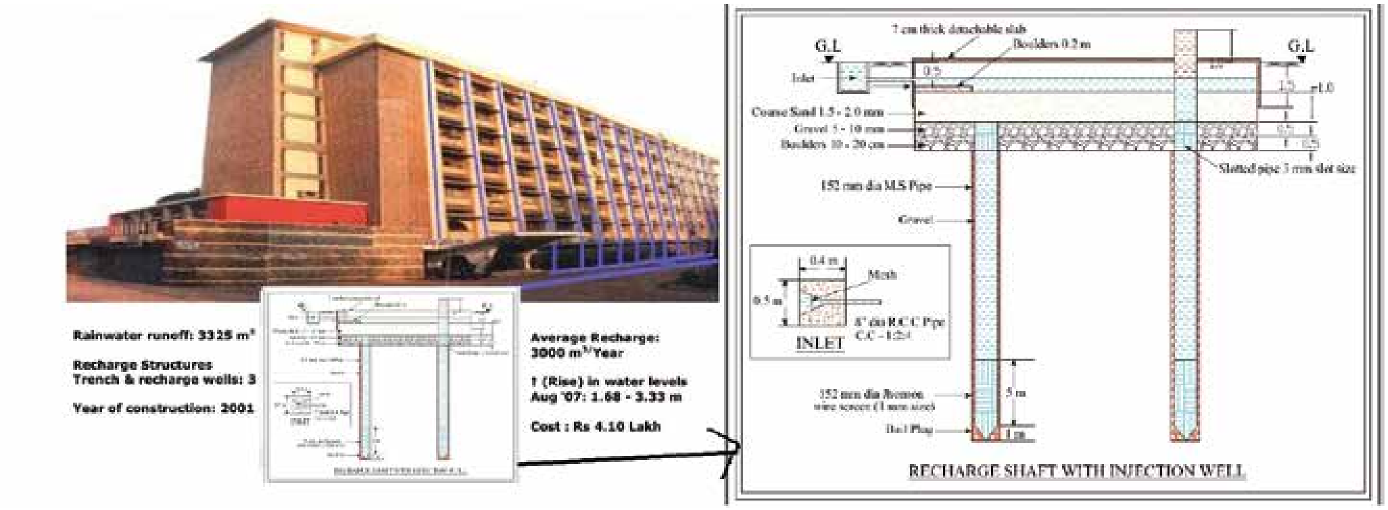


Figure 5. Roof-top rainwater harvesting structure for groundwater recharge in Sham Shakti Bhawan, New Delhi.
Figura 5. *Esturctura para la recogida de agua de lluvia en los tejados y su posterior recarga artificial en Sham Shakti Bhawan, New Delhi.*

1. Alluvial sediments

A. State: Delhi

a) Roof-top rainwater harvesting at Sharam Shakti Bhawan

The Ministry of Water Resources in Sharam Shakti Bhawan covers an area of about 11,965 m^2. The scheme is for utilizing the rainfall runoff generated in the campus area from the rooftop of the buildings and the paved areas. The project was a showcase to utilize runoff from the roof tops and paved areas to recharge the groundwater. For this project, 3 recharge trenches, each with 2 injection wells were constructed. A representative design is given below in Figure 5.

Salient features are:

- Average annual rainfall is 712.2 mm
- Depth to ground water level is 6.0-8.0 m
- Structure proposed: recharge trench with two injection wells
- Expected recharge is about 2,900 m^3/yr
- Total cost of water recharge: $ 0.12 per 1,000 l.

Impact: The impact is the rise in water levels in spite of cumulative pumping around the area and the expected rise in groundwater level is: 1.62 m in 12,000 m^2 area.

b) Recharge structure for the Delhi underground train system

The Delhi underground at present has a total length of 190 km with 5,000 pillars having a distance of 31m between each pillar and it was planned to construct the recharge structures to utilize the monsoon runoff in the elevated sections. A project was initiated which provided information on the runoff and the effectiveness of the recharge structure. The design is given in Figure 6. The construction of many such structures all along the elevated parts of the routes is proposed to mitigate the water shortages. Only a few structures have so far been constructed and no impact study has been done.

c) An artificial recharge scheme for the Indira Gandhi International Airport, New Delhi

The Indira Gandhi International Airport (IGI), Delhi is spread over an area of 22 km^2 of which 3 km^2 is paved, which is likely to be increased to 11 km^2. It is estimated that the monsoon runoff is 4.57 hm^3 which is being regulated via the construction of storm water drains and a recharge structure into the drain. The design of the recharge structure is shown in Figure 7. In the building areas the runoff estimated is 0.03 hm^3/year, for which 20 recharge wells need to be constructed to utilize this potential.

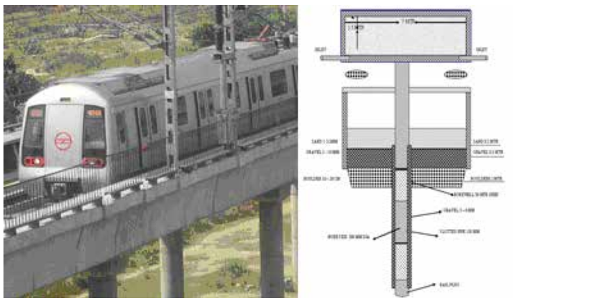


Figure 6. The Delhi underground train system on an elevated structure showing the design of the recharge to groundwater.
Figura 6. *El metro de Delhi sobre una estructura elevada en la que se observa la instalación diseñada para recarga artificial.*

Figure 7. A groundwater recharge structure in the storm water drain, International Airport, Delhi.
Figura 7. *Estructura para recarga artificial mediante drenes del agua de lluvia. Aeropuerto internacional, Delhi.*

B. State: Punjab

Flood mitigation converting a drain into a recharge structure

Groundwater development has been very intensive and the decline of the water table was 10.53m from 1972 to 1988 and subsequently the declining rate has been 0.6 m per year, which increases the energy input to extract groundwater. It was thus planned to have a pilot project to convert a 30.8 km long drain which had an annual water availability of 4.8 hm^3 (Figure 8). For the groundwater recharge 30 vertical shafts with inverted filters, 30 injection wells and a lateral shaft with an inverted filter 300 m long were constructed. It was computed that recharge is about 0.17 m^3 which means an average rise of 0.25 m in an area of 20 km^2.

2. Basaltic aquifers

A. State: Maharashtra

Groundwater recharge by rainwater harvesting

The Basaltic aquifer covers an area of about 500,000 km^2 and some parts of the area have intensive development of groundwater for cultivation of sugar cane, grapes, bananas etc. In order to demonstrate the technology, a watershed was selected where

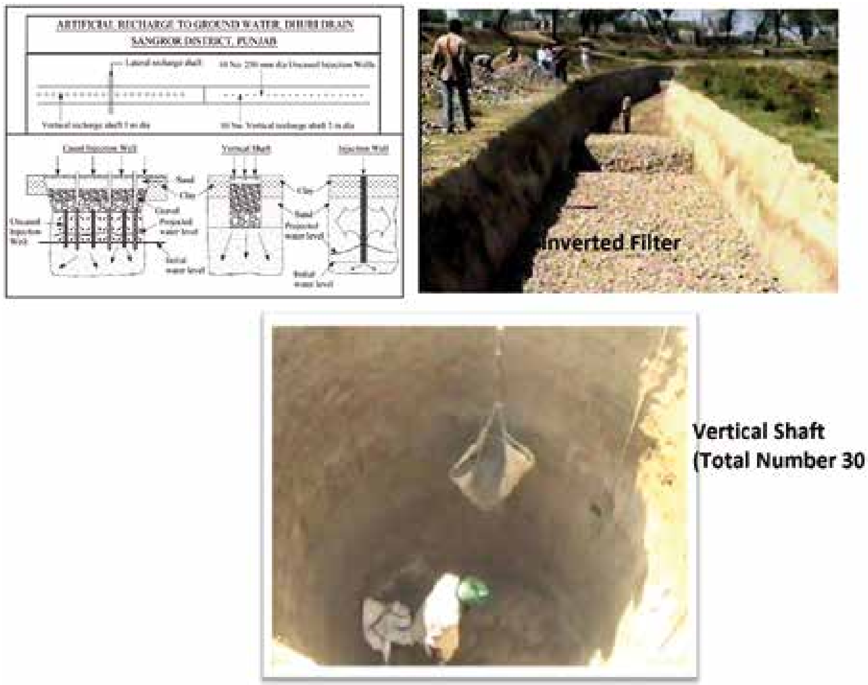


Figure 8. Mitigating floods by converting a 30.8 km storm water drain into a recharge structure, the Dhuri Drain in Sangrur District, Punjab.
Figura 8. *Proyecto para laminar avenidas mediante la transformación de un dren de 30.8 km en una instalación de recarga artificial. Dhuri Drain, en el distrito de Sangrur, Punjab.*

the depth to water table had already reached 40 m below ground level. The water table was declining at the rate 1.0 m per year in some of the locations. TE-11 watershed, Yawal Taluka, Jalgaon district is a critical watershed as regards groundwater development. The depth to water level ranges between 30-40 m below ground level. The water levels are steadily declining at the rate of one metre per year at certain locations. The precarious situation has resulted in the drying up of dug wells and reduced the availability of groundwater for sustaining agriculture.

Features of the scheme are as follows:

- Total watershed area is about 37,890 km^2.
- Average monsoon rainfall of 774 mm
- Monsoon runoff 15,06 hm^3/yr
- Total available surplus runoff is 14.51 hm^3/yr
- The structure proposed: 2 percolation tanks and 5 recharge shafts with sub-surface storage potential availability of 153 hm^3 (Figure 9). The large potential is because of the large sub-surface space available i.e. 375 km^2 having an average thickness of 12 m of desaturated aquifers.

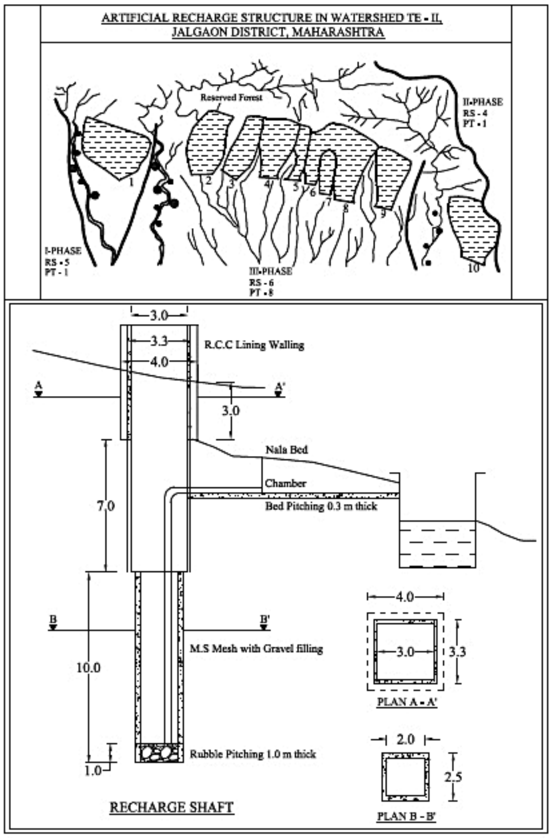
Impact: The impact shows that the decline of water level has been curtailed and there is a rise in water level of about 1.5 m.

3. Granitic aquifers

State: Karnataka

Recharge *through check dams*

The Indian peninsular is mostly covered by granitic rocks which constitute poor to moderate aquifers. The rainfall is mostly conserved through the construction of irrigation tanks. In view of the undulating topography, it was found that the check dams would be useful structures for water storage and recharge of groundwater. A pilot project was implemented in the water starved University Campus which guarded the limited water supply from municipal corporation. The implementation of the scheme helped to conserve 22,000 m^3 of water. The scheme then helped to conserve a total **of** 43,290 m^3, 50% of which recharged the depleting aquifer. The features of the project are given in Table 3.



Catchment details	Check Dam 1	Check Dam 2	Check Dam 3
Area (sq. m)	260000	340000	410000
Yield (cu.m)	14860	19430	23430
Water available for recharge 75% of yield (cum.m)	11150	14570	17570

Table 3. Salient features of the recharge scheme.
Tabla 3. *Cifras del esquema de recarga.*

Figure 9. An artificial recharge structure in TE-II watershed showing the design of recharge shafts (5 in total), Jalgoan District, Maharastra.
Figura 9. *Instalación de recarga artificial en la cuenca TE-II compuesta por zanjas. Distrito de Jalgoan, Maharastra.*

4. Coastal areas

State: Orissa

Arresting salinity intrusion and artificial recharge to ground water via creeks

Groundwater development in coastal tracts invariably results in sea water intrusion which affects the quality of shallow aquifer systems. The project has been conceived to utilize the minor creeks and *nalas* or drains for storing fresh water for irrigation and injecting fresh water into the saline water bearing shallow aquifers so that the salinity of the water can be reduced and make it useful for irrigation and other purposes. The study pertains to 5 creeks in the Orissa coastal areas where because of the saline intrusion, the local community faced problems for irrigation and drinking water (Figure 10).

In connection with arresting saline intrusion, the following work was carried out:

- De-silting and renovation of the creeks by excavation.
- Remodelling of old sluices and the construction of new ones.
- Construction of 15 small bridges and one high level bridge over the creeks for connectivity.

Table 4 and Table 5 give the impact assessment of salinity intrusion and the increase in irrigation potential and impact assessment details for creek irrigation, respectively.

5. Sub-surface dikes

State: Kerala

The average annual rainfall of 3,000 mm in Kerala is 3 to 5 times more than many other states. However, in Kerala, rainwater is not retained very much on the land due to the steep/undulating topography

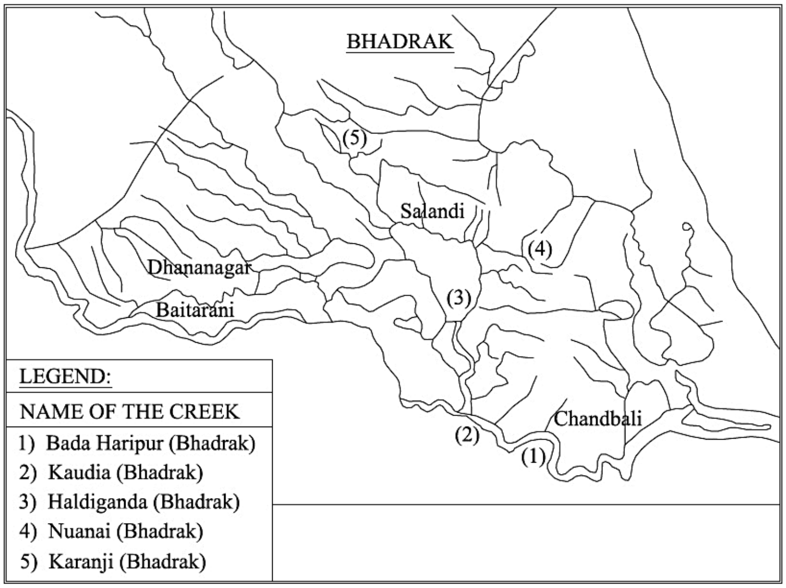


Figure 10. Location of different creeks modified for arresting the saline intrusion in parts of the coast, Bhadrak District, Orissa.
Figura 10*. Localización de diferentes ríos que se han modificado para luchar contra la intrusión marina en parte de la costa. Distrtio de Bhadrak, Orissa.*

Sl . No	Name of Creek	Water Availability		Increase in Irrigation Potential m³
		Pre- Execution m³	Post- Execution m³	
1	Haladiganda	104688.40	563115.80	458478
2	Kaudia	22660	115640	93000
3	Badaharipur	14960.25	1186380	170000
4	Nuanai	123150	284246	160000
5	Karanji	30000	810000	510000

Table 4. Impact assessment of arresting saline intrusion (under the Central Sector scheme).
Tabla 4. Evaluación del impacto de la intrusión salina (en las condiciones del esquema del Sector Central).

Effects \ Creeks		Haldiganda	Badaharipur	Nuanai	Kaudia	Karanji
Salinity Ingress Check		Completely Checked and Multiple usage of creek water done	Completely Checked and Multiple usage of creek water done	Completely Checked and Multiple usage of creek water done	Completely Checked and Multiple usage of creek water done	From Mantei river completely checked. 1950 Ha made free of Salinity & Water Logging. Multiple usage of creek water done
Impounding Capacity (CuM)		4,65,000	1,20,000	1,70,000	1,60,000	1,96,875
Ayacut Irrigated (Ha)	**Khariff**	367	1200	1456	1120	810
	Rabi	2708	424	742	1429	142
Increased Irrigation Potential (HaM)		460	93	170	160	810
Ground Water Recharge		All along the Creek network	All along the Creek network	All along the Creek network	All along the Creek network	17.5 Km Tract Recharged

Table 5. Impact assessment details under the creek irrigation scheme.
Tabla 5*. Detalles de la evaluación del impacto por cada cuenda de riego.*

and the low water-holding capacity and the shallow depth of the topsoil. Sub-surface dikes or under-ground dams form a sub-surface barrier across stream which retards the base flow and stores water upstream below the ground surface. The site where the sub-surface dike is proposed should have a shallow impervious layer with a wide valley and narrow outlet.

After selecting a suitable site, a trench 1-2 m wide is dug across the breadth of stream down to the impermeable bed. The trench may be filled with clay or a brick/concrete wall up to 0.5 m below the ground level (Figure 11).

Salient features of the sub-surface dike in Kerala

- Average rainfall: 1,155 mm.
- Average number of rainy days: 108.
- Lowest rainfall: 835.6 mm (during 1976).
- Structure: a sub-surface dike with 3 piezometer sets
- Cost benefit ratio of 1:1.29.

Impact: The impact analysis shows an increase of 4,000 cubic metres upstream, with a rise of 2 m in the groundwater levels.

Figure 11. Design of a sub-surface dike for management of the base flow to create storage and recharge to groundwater, Palghat District, Kerala.
Figura 11*. Diseño de diques subsuperficiales para la gestión del caudal base con objeto de inducir almacenamiento subterráneo y recarga artificial. Distrito de Palghat, Kerala.*

Other artificial recharge schemes

The two schemes in operation are:

(i) Dug-well recharge

(ii) Repair, renovation and restoration of village water bodies.

These schemes are for the recharge of groundwater, either directly or indirectly through seepage from the water bodies.

I. Dug-well Recharge

In addition to the implementing large projects, the Indian Government has recently launched a programme to assist poor farmers to recharge 0.7 million open wells so that the depleted water table is recovered from recharge using runoff from the field areas. A representative dug-well recharge diagram is shown in Figure 12. The scheme is in operation and will be used to complete for 0.7 million dug-wells /open wells.

II. Repair, renovation and restoration (RRR)

The village ponds (water bodies) are the lifeline for rural areas and have served the purpose of irrigation and domestic water supply over the last two thousand years. These water bodies are also very useful for groundwater recharge particularly in locations above saline-water aquifers. Because of the spurt in the construction of shallow and deep tub wells to meet water requirements, these water bodies were becoming defunct. The Indian Government has initiated a scheme to restore 1 098 water bodies in 26 districts of 15 States to create 78,000 ha. of additional irrigation potential.

III. Recharge canals

In another initiative, the Government of Gujrat has constructed an exclusive recharge canal named "Sujlam Suflam", with a length of 337 km, to recharge the depleting groundwater table in arid and semi-arid areas and to act as drought proofing. Water in the canal is released from the surplus storage in nearby dams.

Figure 12. Schematic diagram for dug-well recharge.
Figura 12. *Diagrama esquemático de un pozo excavado para recarga.*

IV. Water conservation in island areas

The island area of Andaman & Nicobar receives an average annual rainfall of 3000 mm, but the availability to meet drinking water requirements is inadequate. To increase the area under irrigation and to sustain the domestic water supply, a number of schemes have been initiated. One such scheme has been the construction of check dams. Table 6 gives the construction of check dams in southern Andaman, utilizing the monsoon runoff.

Initiatives and measures for conservation

A. Government Intervention

In order to encourage rainwater harvesting both for water conservation and recharge and get the various programmes ready for implementation, the following two high level committees have been set up:

1. **The Advisory Council on the Artificial Recharge of Ground Water**: the Indian Ministry of Water Resources constituted this committee in 2006; the members are from government institutions, NGOs and stake holders.
2. **Water Conservation and Management:** The Parliament set up a forum on water conservation and management on 12 August 2005 to invite the parliamentarians (elected representatives) to identify problems relating to water resources including artificial recharge, make suggestions/ recommendations for consideration and appropriate action by the government/organizations concerned and to encourage members of Parliament to augment water resources in their respective constituencies.
3. The Ministry of Water Resources has instituted annual awards, namely the Ground Water Augmentation Awards (Bhoomijal Samvardhan Puraskar) and the National Water Award in 2007 for the best structures and also for awareness programmes via school paintings. These awards have motivated stakeholders to take up water conservation and recharge projects in a significant way.
4. To further to promote rainwater harvesting in urban areas, the subject has been included in urban bylaws which make it mandatory to have rainwater harvesting in all the houses covering

Sl . No	Location	Width (m)	Depth of water (in m)	Volume of water impounded (M^3)	Irrigation potential created (Hectare)	Cropping pattern
1	Beadnabad-I	4.46	0.9	137.68	6.0	Betel vine,Ladies finger,pumpkin,ridge gourd,cowpea,Radish
2	Kodiyaghat	4.50	0.55	24.85	5.0	Cowpea,Betel gourd, Ladiesfinger,Radish, Bean,French bean, Bottle gourd,pumpkin
3	Maccapahar-I	3.8	0.88	26.51	3.0	Drumstick,Betel vine, Areca nut
4	Maccapahar-II	4.0	0.7	34.66	4.0	Coconut,Areca nut, Cowpea, Ladies finger,ginger
5	Maccapahar-III	6.02	1.2	40.47	4.0	Coconut,Areca nut, Cowpea, Ladies finger
6	New Bimblitan-2	2.10	1.0	11.52	2.5	Coconut,Areca nut, Cowpea, Ladies finger
7	Calicut-II	8.5	1.0	119.98	10.0	Coconut,Areca nut

Table 6. Rainwater harvesting through check dams in southern Andaman.
***Tabla 6**. "Rainwater harvesting" mediante presas de control en el sur de Andaman.*

an area of more than 100 m^2 and in all the plots with an area of more than 1 000 m^2 that are being developed. Some of the state governments have also given incentives for groundwater recharge through rainwater harvesting

B. Constraints

1. **Construction of check dams across different drainage systems:** check dams or *anicuts* are the most common form of water conservation and indirectly recharge to the aquifer systems constructed across different streams. In order to meet local water demand, check dams of variable length and height are constructed to store maximum amounts of water irrespective of the runoff available in the respective catchment area. This has restricted the flow of water to historical water tanks/reservoirs constructed for domestic water supply. For want of enough flow to these tanks/reservoirs, they started drawing up which affected the water supply to the communities. As the issue was critical, a court of law directed to keep the height of the dam to the maximum of 2m in Rajasthan. This is one of the conflict areas which need to be resolved for the various programmes related to the construction of check dams in water scarcity areas. This is shown in Figure 13, illustrating the construction of check dams irrespective of drainage systems and catchment areas.
2. **Water Quality Issues**: At present, the momentum is towards using the surplus monsoon runoff for recharging the depleting aquifers but with no consideration to the water quality of the source water. Therefore it is not only that the strainers of the recharging well are getting clogged but the aquifers are getting polluted with pathogens which cause water borne diseases. In the construction of recharging wells, different designs are used as there is no code of practice. In the de-silting chambers, various materials are used which cause water quality problems to the recharged aquifers.
3. **Database Issues:** At present the database showing the number of different types of recharge/ conservation structures completed or under completion across the country does not exist, therefore, it is difficult to quantify how much quantity of water is going into aquifers. The data-

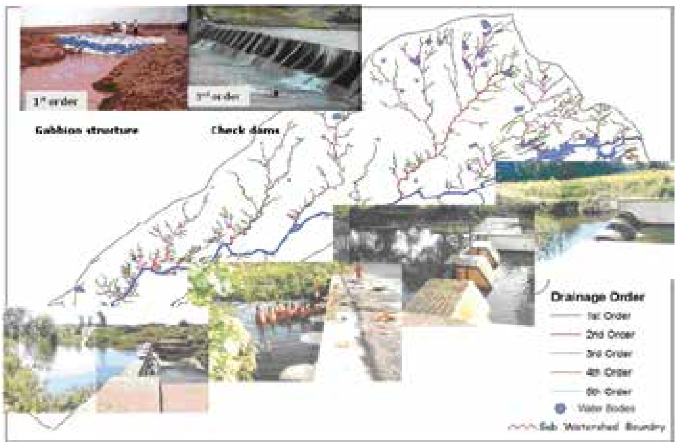


Figure 13. Illustrated diagram showing the construction of check dams across different streams.
Figura 13. *Diagrama en el que se muestra la construcción de presas de control a lo largo de diferentes cauces.*

base is an important tool for calculating the cost/benefit ratio of different projects. There is thus a need to set up a national database.

4. **Research and Development Issues:** Although a number of projects of different dimensions are being implemented there is no central or state institution to provide guidance on the design of the recharge structures and to monitor their functioning. The post monitoring of the completed projects is not mandatory. Therefore, many of the structures might have become more or less defunct, requiring rehabilitation and continuous maintenance. Research and development projects are approved for financial assistance but there is need to take the technology forward in the case of other uses of water i.e. storm water, reclaimed water.
5. **Ownership of Conserved Water:** In many of the water scarcity areas, recharge projects have been set up with financial assistance from the Government, but the conserved/storage water is being used for water intensive crops even if the communities have no source of drinking water. It is thus important to provide guidelines for the ownership of recharged water and also its use. It is opined that the first use of recharge water should be for domestic use.

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