Managed Aquifer Recharge

N. C. GHOSH
National Institute of Hydrology, Roorkee

MANAGED AQUIFER RECHARGE (MAR) – DEFINITION AND USE

Managed Aquifer Recharge (MAR) describes intentional storage and treatment of water in aquifers for subsequent recovery or environmental benefits (Dillion et al, 2009). The term "Artificial Recharge (AR)" commonly used in India also describes the similar activity as in MAR without consideration of quality of water resources, however, the term 'MAR' so far has not been as popular as the term 'AR'.

Stating more elaborately, MAR is the process of adding a water source including recycled water to aquifers under controlled conditions for withdrawal at a later stage, or used as a barrier to prevent saltwater or other contaminants from entering the aquifer. Water can be recharged by a number of methods including infiltration via basins or galleries or by the use of injection wells.

AR can be defined in many ways. Stating in simple words, AR is a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer. Except the contemplation on quality of water, MAR and AR have same physical significance and purpose.

MAR as part of the groundwater manager's tools may be useful for replenishing and re-pressurising depleted aquifers, controlling saline intrusion or land subsidence and improving water quality through filtration and chemical and biological processes. On its own it is not a cure for over-exploited aquifers, and can merely enhance volumes of groundwater abstracted. However, it may play an important role as part of package of measures to control abstraction and restore groundwater balance. MAR can be used to address a wide range of water management issues as given below and also depicted in Fig 1.

- Storing water in aquifers for future use
- Security and enhancing water supplies
- Smoothing out supply and demand fluctuations
- As part of integrated water management strategy (IWRM)
- Stabilizing and rising groundwater levels in depleted aquifers
- Improving groundwater quality
- Situations where no suitable surface storage site available
- Maintenance of river base flow and environmental flow
- Impeding storm runoff and soil erosion
- Reducing loss through evaporation
- Preventing saline water intrusion in coastal aquifers and land subsidence

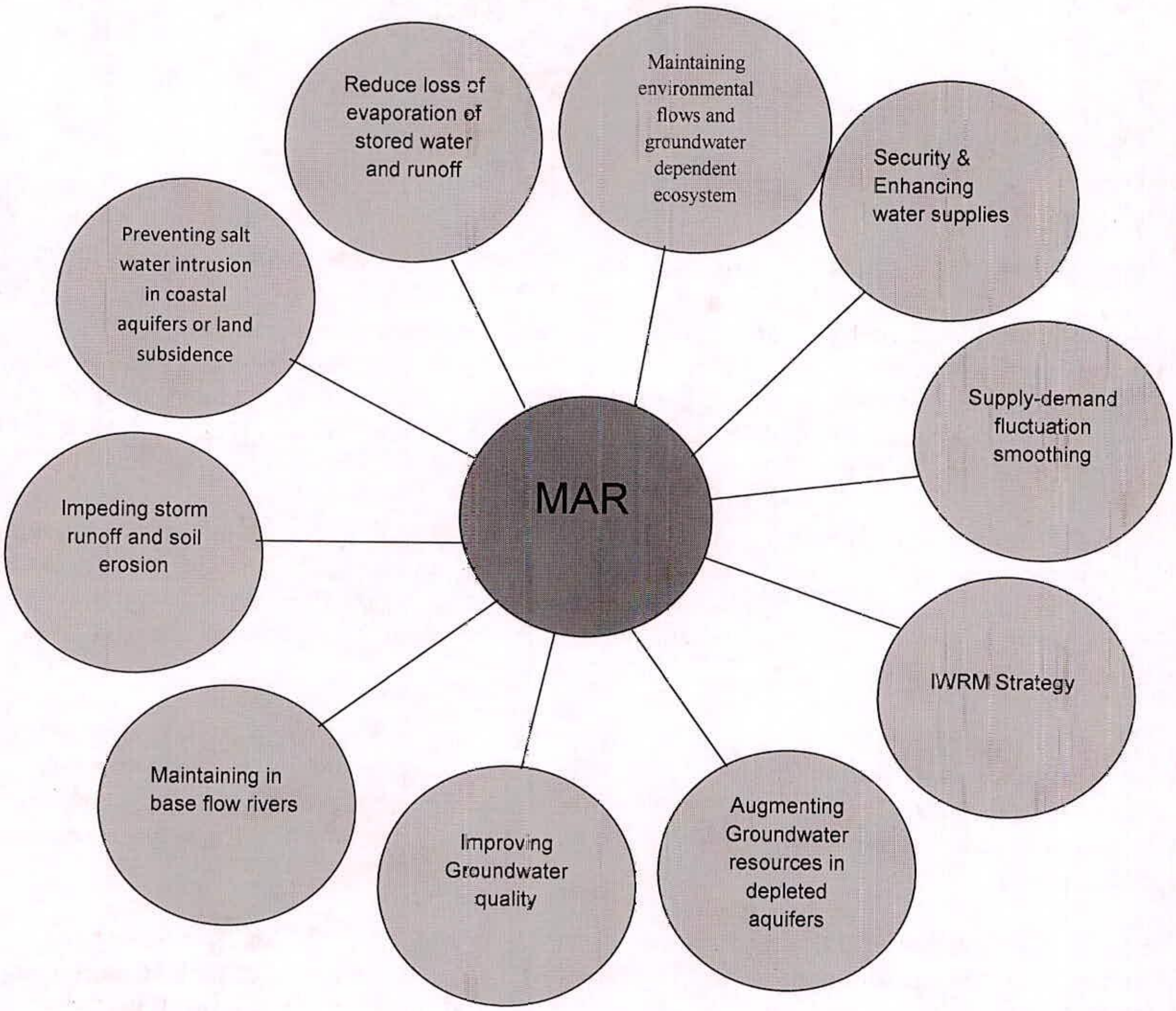

Fig. 1 Some important groundwater conservation and management issues, which can be addressed by MAR.

TYPES OF MANAGED AQUIFER RECHARGE

A wide range of methods are in use for recharging aquifer for to meet variety of local problems. These are shown in Figs. 2 and 3 as examples.

The descriptions of different recharging methods are in use in different countries are as follows:

Aquifer storage and recover (ASR) : injection of water into a well for storage and recovery from the same well (Figure 3). This is useful in brackish aquifers, where storage is the primary goal and water treatment is a smaller consideration (e.g. South Australia).

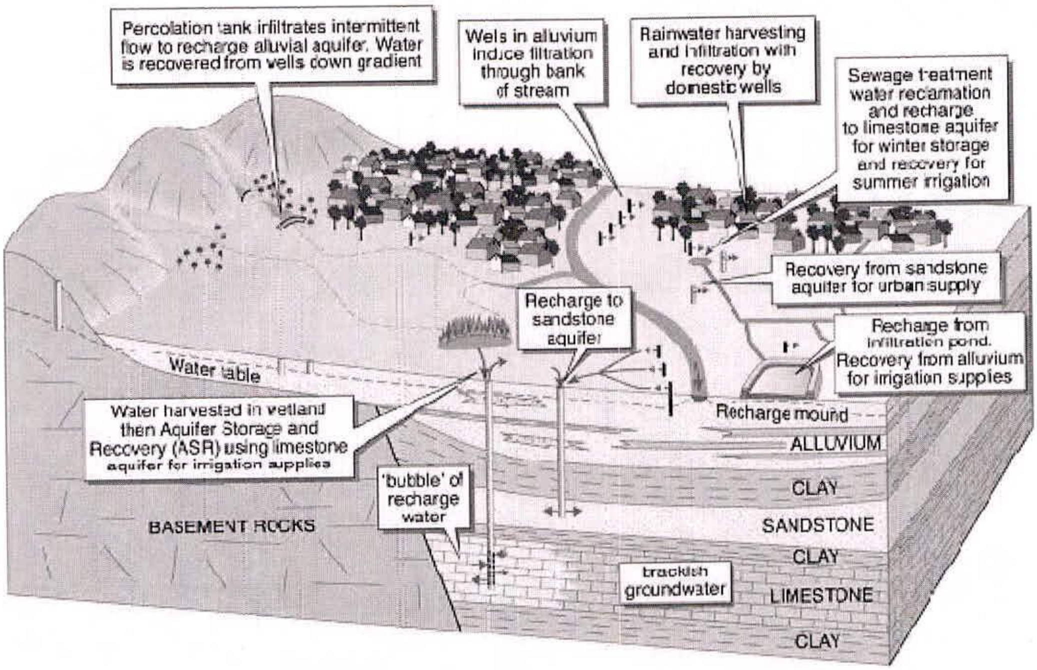

Fig. 2 Variety of recharge methods and water sources making use of several different aquifers for storage treatment with recovery for a variety of uses (Adapted from Gale, 2005).

Aquifer storage, transfer and recover (ASTR) : involves injecting water into a well for storage, and recovery from a different well (Figure 3). This is used to achieve additional water treatment in the aquifer by extending residence time in the aquifer beyond that of a single well (e.g., South Africa).

Infiltration ponds : involve diverting surface water into off-stream basins and channels that allow water to infiltrate through unsaturated zone to the underlying unconfined aquifer (e.g., India and Queensland, Australia).

Infiltration galleries : underlying trenches in permeable soils to allow infiltration through the unsaturated zone to an unconfined aquifer (USA).

Soil aquifer treatment (SAT) : treated sewage effluent is intermittently infiltrated through infiltration ponds to facilitate nutrient and pathogen removal in passage through the unsaturated zone for recover by wells after residence in the unconfined aquifer (Northern Teritory, Australia).

Percolation tanks or recharge weirs : check dams built in ephermal streams detain water which infiltrate through bed to enhance storage in unconfined aquifers (e.g., Queensland Australia).

Rainwater harvesting for aquifer storage : rooftop rainwater runoff is diverted into a well, sump or cassion filled with sand or gravel allows to percolate to water table where it is collected to pumping from a well (e.g., India and West Australia).

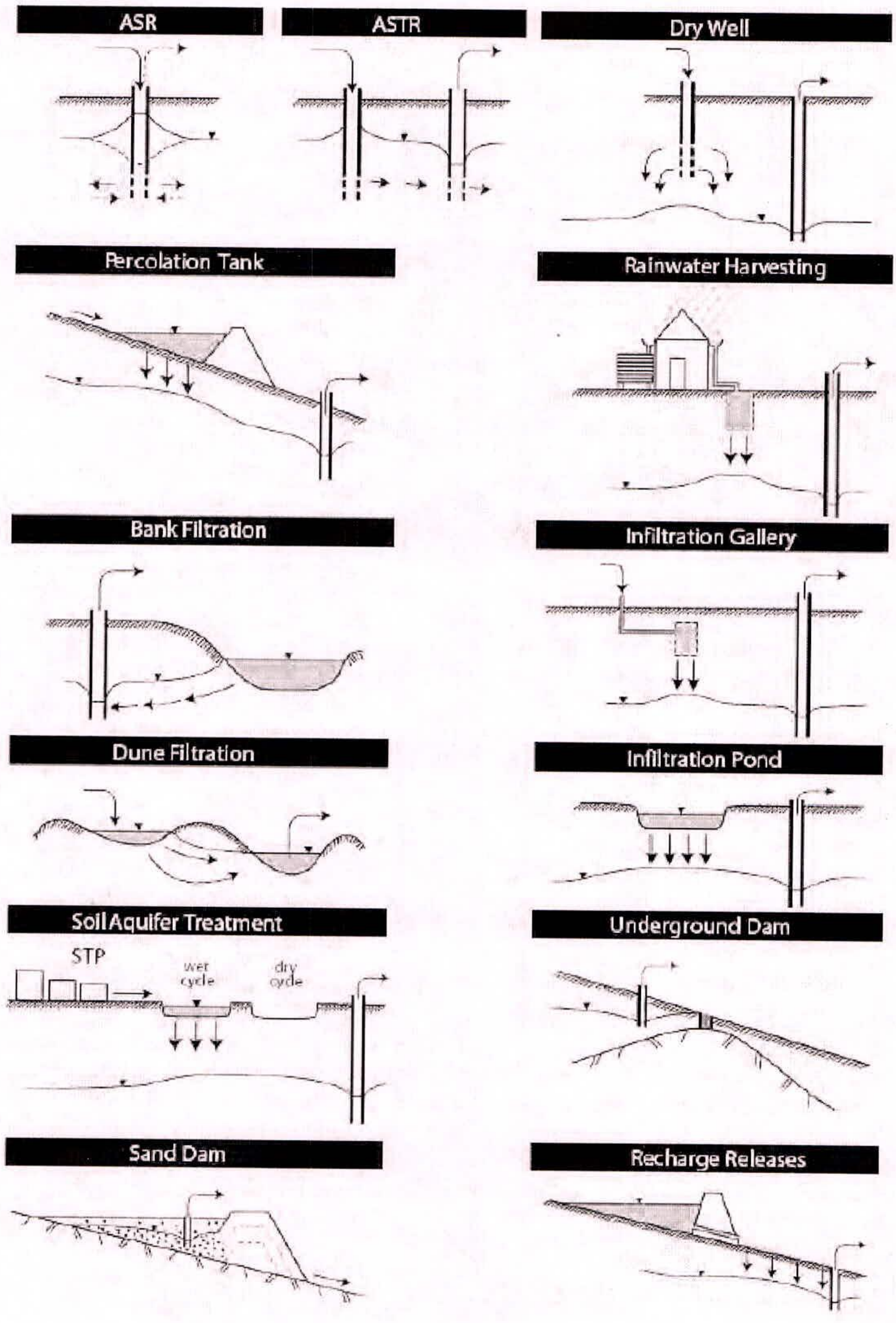

Fig. 3 Schematic of types of Managed Aquifer Recharge (Source: Dillion, 2005)

Bank filtration(BF) : extraction of groundwater from a well or cassion near or under a river or lake to induce infiltration from the surface water body thereby improving the quality of water recovered(e.g., Germany).

Dry wells: typically shallow wells where water table are very deep, allowing infiltration of very high quality water to the unconfined aquifer at depth (e.g, USA).

Dune filtration: infiltration of water from ponds constructed in dunes and extracted from wells or ponds at lower elevation for water quality improvement and to balance supply and demand(e.g., The Netherlands).

Underground dams : in ephemeral streams where basement highs constrict flows, a trench is constructed across the streambed, keyed to the basement and backfill with low permeability material to help retain flood flows in saturated alluvium for stock and domestic use (e.g., Kenya).

Sand dams: built in ephemeral stream beds in and areas on low permeability lithology, these trap sediment when flow occurs, and following successive floods the sand dam is raised to create an aquifer, which can be tapped by wells in dry seasons (e.g., Namibia).

Recharge releases : dams on ephemeral streams are used to detain flood water and uses include slow release of water into the streambed downstream to match the capacity for infiltration into underlying aquifers, thereby significantly enhancing recharge (e.g., South Africa).

Selection of suitable sites for MAR and choice of method depends on the hydrogeology, typography, hydrology, and landuses of the area. MAR is in wide use in many countries to enhance water supplies, particularly those in semi-arid and arid areas, but also in humid areas, primarily for water quality improvement.

CRITERIA FOR SELECTING MAR PROJECTS

There can be several criteria fixed worldwide for selecting a MAR project. The Central Ground Water Board (CGWB) has given certain criteria for selecting the potential areas for implementating the MAR structures. These are areas where

- Groundwater levels are declining on regular basis.
- The availability of ground water is inadequate in lean months.
- A substantial amount of aquifer has already been desaturated.
- The site is adjacent to a leaky fault or a semi-confining layer containing poor quality of water
- The aquifer contains poor quality water and is highly heterogeneous or has a high lateral flow rate.
- Aquifers show saline water intrusion.

Factors Influence Feasibility and Performance of MAR

- Hydrogeology
- Climate and Hydrology

Hydrogeological settings

The physical success of a MAR scheme depends largely on the local hydrogeological conditions. These determine the ability of the recharge water to percolate through the unsaturated zone and the ability of the aquifer to store the recharge water.

The main factors to consider for hydrogeological settings are:

- Physical and hydraulic boundaries of the aquifer and degree of confinement.
- Hydrogeological properties of the aquifer and overlying formations.
- Hydraulic gradient in the aquifer.
- Depth to aquifer/piezometric surface.
- Groundwater quality.
- Aquifer mineralogy.

Climate and Hydrology

- Climatic conditions in the application site have an important role in determining the dimensions and type of structures that need to be implemented. The climatic factors are:
- Mean annual rainfall (for determining size of the structure).
- Number of rainy days.
- Shifts in the seasonal patterns (alternate dry and wet season, water table fluctuation, etc.)
- Frequency of high intensity rainfall (storage capacity, pre-treatment capacity and efficiency)
- Variability in temperature (evaporation, hydrogeochemical rates, etc.)

Hydrology is an important factor in locating an appropriate areas for MAR and also in determining the amount of wateravailable for recharge. Availability of naturally suitable sites is always suitable for bringing down the operation and maintenance cost.
The most important hydrological characteristics that influence MAR are:

- Terrian characteristics (topography, elevation, slope,etc.)
- Land-uses (agriculture, urban areas, barren land, etc.)
- Vegetation cover (forest, grass land, etc.)
- Flow availability and rate in streams (perennial, ephemeral, large/small rivers)
- Conveyance system for bringing the water (gravity flow, energized pumping, suitability for canals, pipe networs,etc.)

Water Quality Issues in MAR

The quality of the groundwater, both natural baseline and that altered by Man's activities, and the interaction with the recharged water need to be understood and managed. A pre-requisite for MAR of groundwater is the availability of a source water of suitable quality in sufficient quantity. Several source of water can be considered for use as recharge water, namely surface water, runoff volume, treated effluent or potable supply water.

Constraints and Disadvantages

Although MAR has several advantages, a number of constraints and disadvantages are also reported by various researchers during the implementation. The most commonly encountered problems in MAR are as follows:

- Clogging.
- Uncertainity in aquifer hydraulics.
- Uncertainity of complete recovery of stored water.
- Uncontrolled recovery by different users.
- Regularity constraints.
- Damage to aquifers.
- High outlay before feasibility of ASR can be established.
- Operational issues.

WHY IS MAR NECESSARY IN INDIA?

- India is now the biggest groundwater user for agriculture in the World (Shah, 2009).
- Groundwater has been the most preferred source for drinking water in India, particularly in rural and peri-urban areas.
- Statistics revealed that over the last 50 years, number of groundwater structures have increased manifolds from 3.9 million in the year 1951 to 18.5 million in the year 2001 out of which about 50% accounts tube wells (Figure 4) [Minor Irrigation Census, 2001]. In all likelihood, the number of groundwater structures is now expected to be around 27 million (Shah, 2009).
- The poor public irrigation and drinking water delivery, new pump technologies, flexibility and timeliness of groundwater supply, government subsidy on electricity in the rural areas, and lack of groundwater regulation legislation, have given rise to preferential growth of groundwater uses in India.
- The growth in the groundwater structures had also increased the groundwater based irrigation potential, and at the same time, declined the share of surface water uses for irrigation from 60% in the 1950s to 30% in the first decade of the 21st century (Figure 5).
- Natural recharge measurements carried out in about 20 river basins suggested that only about 5 to 10 percent of the seasonal rainfall is contributed as annual recharge in the peninsular hard rock regions, and is about 15 to 20 percent of the rainfall in the alluvial areas (Athavale et al 1992). Rapid urbanization and land use changes have reduced drastically the infiltration rate into the soil and are diminishing the natural recharging of aquifers by rainfall. This has created lowering of water table, drying of wells and deterioration in quality.
- Today, groundwater is the source for more than 85% of India's rural domestic water requirements, 50% of urban water, and about 60% of irrigation demand (CGWB, 2011; Task Force, 2009).

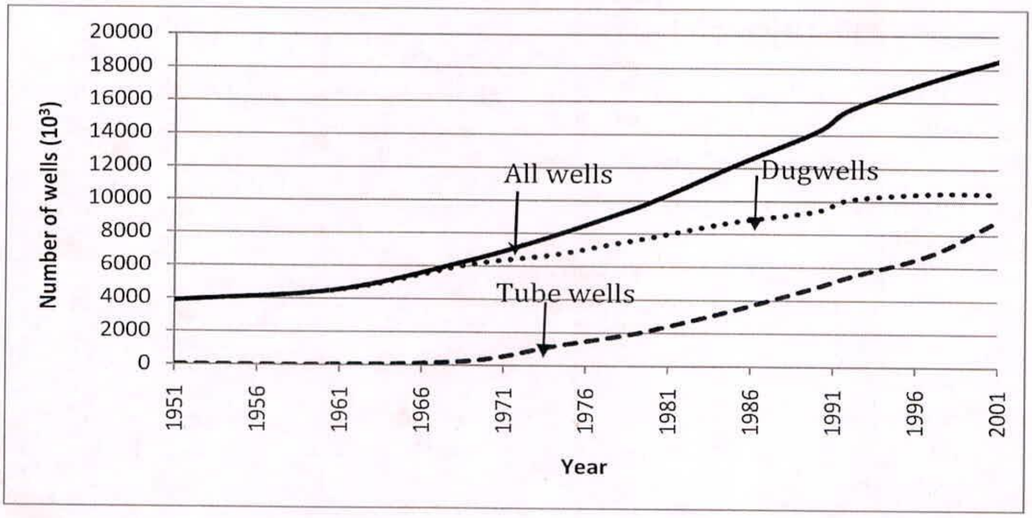

Fig. 4 Growth of groundwater structures in India (1951-2001) [Source : Graph prepared using data of Minor Irrigation Census, 2001 & data compiled by Singh & Singh, 2002] .

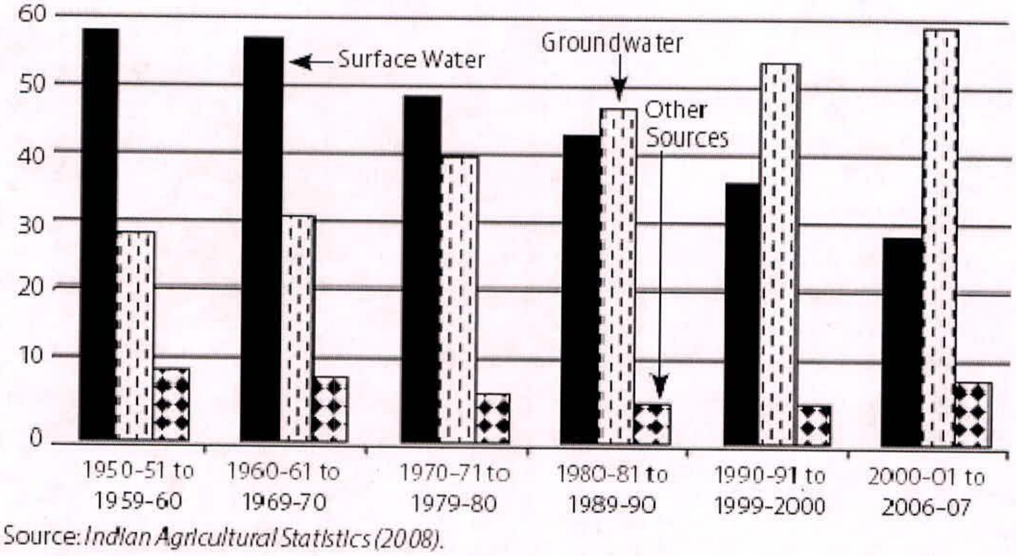

Fig. 5 Decade-wise share of surface water and groundwater in net irrigated area in % (adopted from Vijay Sankar et al., 2011)

- Groundwater is mostly preferred in rural area primarily because;
  - ➢ rural people have a common notation that groundwater is less risk free from pollution than surface sources of water,
  - ➢ it is ubiquitous, and can be drawn on demand in any quantity wherever and whenever required.

- Indiscriminate extraction and development had led substantial ground water table depletion in many parts of India both in the hard rocks and alluvial areas. Long-term decline of ground water table had been reported mostly from the states of Rajasthan, Gujarat, Tamil Nadu, Punjab, Delhi and Haryana.

    - For example, out of 5723 assessment units (Blocks/ Mandals/ Talukas) in different states by CGWB(2007), 839 units (15%) had been categorised as 'overexploited' with ground water extraction more than the net annual recharge, and about 4% has been categorized as 'critical', extraction between 90% and 100 % of the net annual recharge. And 30 blocks had been categorized as the saline ground water (CGWB, 2007).

- Groundwater contamination from the sources of both geogenic and anthropogenic origin such as, Arsenic, Fluoride, Salinity, and Nitrate is another threat to the availability of safe groundwater resources.

There is no reason to believe that the growth of groundwater structures and uses of groundwater are going to slow down in future, unless otherwise controlled by enforcing legislation, rather will continue to rise because of growing concern on water quality, socio-economic improvement and socio-cultural dimensions of the rural sector.

Presently, India's irrigation water availability from both surface water storages and groundwater availability is about 541 BCM in which groundwater is 221 BCM. By the years 2025 and 2050, these are projected to be 916 BCM and 1032 BCM, respectively. If the current state of affairs are continued, groundwater availability for irrigation can be increased to 236 BCM (26%) by the year 2025 and 253 BCM (25%) by the year 2050.

On the other hand, runoffs from rainfall are mainly available during four monsoon months and scope for catching runoffs by creating large scale surface water storages is restricted by surface topography; large amount of monsoon surface runoffs of the order of 1548 BCM annually flows out from the basins to sea as unutilized; excess groundwater withdrawal depletes groundwater table and thereby creates more space for aquifer storages, etc.

Therefore, there is need to conserve monsoon runoffs and store them appropriately for subsequent uses during non-monsoon months to meet the growing demands of water for various uses. MAR is one of the ways to conserve excess surface runoffs as groundwater storage and can address the lack of groundwater availability. The main advantages with MAR are; aquifer storages are naturally available and there is no need for additional large scale investment, groundwater moves slowly in the aquifer, therefore, storages are largely available in local scale, etc.

It has been estimated by CGWB (2007) that an area of 4,48,760 km2 about 14% of total land area of India is suitable for MAR and a volume of 36 BCM of water can be recharged annually. This volume is equal to about 16% of 221 BCM of groundwater that is currently utilised annually for irrigation.

MAR Practices in India

India's rural villages, in different regions of the country, have a long tradition of practising rainwater conservation, harvesting snow and glacier melt water, and judicious use of groundwater by employing indigenously developed techniques and methods for fulfilling requirements of agriculture and drinking. Although those schemes were known by different names in different parts of the Country, however, their purposes and uses are similar to the MAR.

India's strong cultural heritage also cites an excellent example of practising MAR. Temple tanks are part and parcel of many village eco-systems; there are no village without temple and no temple without tank; these tanks act as aquifer recharge structures and help in maintaining groundwater level throughout the year. More than 500, 000 tanks and ponds, big and small, are dotted all over the country and more so in the peninsular India. These tanks were constructed thousands of years ago for catering to the multiple uses of irrigated agriculture, livestock and human use such as drinking, bathing, and washing. Many drinking water wells are located within the tank bed and on tank bund to provide water supply throughout the year with artificially recharged water from the tank water in to these wells.

In addition to those, for groundwater development and conservation measures particularly in water scarce areas, groundwater table depleted aquifers, and in coastal aquifers to arrest ingress of seawater intrusion both state and central governments, non-governmental organizations, village community, etc. from time to time had promoted artificial groundwater recharge schemes.

Therefore, practise of MAR in India has a long history and can be recognized as an old age technique. With the passage of time, the importance of these old age techniques has been realized and presently promoted on large scale as a government supported scheme for conservation of rainwater and groundwater recharge. A compilation of various traditional rainwater harvesting (RWH) and groundwater recharge structures practised in various places in India is given in annexure I.

Considering the above historical background of MAR practises in India, its spread can broadly be classified under three phases (Sakthivadivel, 2007):

- The first phase relates to the period before the green revolution when limited exploitation of groundwater was taking place, i.e., before 1960,
- The second is the period between 1960 and 1990, where intense groundwater exploitation took place with signs of over exploitation,
- The third is the period from 1990 to date, when water scarcity is increasing alarmingly and the groundwater level is declining in certain pockets.

The First Phase - Period before 1960

Traditional water harvesting methods were given impetus through unorganized movements by the local communities, aided by kings and benevolent persons to meet the local requirement. During this period, there was very little knowledge-based input from the government, non-government organizations and the scientific community to provide assistance for understanding and putting into practice a systematic artificial recharging, and up-scaling. Yet, the local community used their intimate knowledge of terrain, topography and hydrogeology of the area to construct and operate successful artificial recharge structures. Very little understanding existed about the consequences and the knowledge required for artificial recharging of aquifers.

The Second Phase – Period between 1960 and 1990

During this period, both the public and the government had started realizing the importance of recharging of aquifers to arrest the decline in groundwater and maintain the required groundwater levels. As a consequence, pilot studies of artificial recharging of aquifers were carried out by a number of agencies and the technical feasibility of artificial recharging and recovery of recharged water had been established.

The Third Phase – Period from 1990 to date

Water scarcity, continuous droughts in certain pockets and the continuously declining groundwater levels in many parts have forced both the public and the government to become aware and to take up artificial groundwater recharge on war footing. Three major activities took place during this period; one is large scale taking up of artificial recharge scheme by public through dug and bore wells, check dams and percolation ponds, followed by the government joining hands with the local community in implementing such schemes on a mass scale. The second is the action taken by state government such as Tamil Nadu, in promulgating the groundwater regulation act pertaining to metropolitan area and ordering the community to implement rainwater harvesting schemes and artificial groundwater recharge on a compulsory basis in the metropolitan area. The third one is the awareness created among the public by the non-governmental organizations.

Common Techniques Employed for Artificial Recharge in India

Based on a survey carried out between 1980 and 1985, the Central Ground Water Board (CGWB) had identified a number of techniques commonly used and suitable for artificial recharge in India. The suitability of these techniques (Table1) had been identified based on the different hydrogeological and topographic conditions.

Ministry of Rural Department, Government of India (2007) had published a document entitled "Bringing sustainability to drinking water systems in rural India" compiling experiences and studies from all parts of the country on traditional wisdom and best practices in water management with modern technologies and scientific understanding focusing mainly on rainwater harvesting and groundwater recharge. The document provides an excellent state-wise compilation of information on "artificial recharge structures" and their performances.

The CGWB in 1996 (CGWB, 1996) had prepared a Perspective Plan for Artificial Recharge to use surplus non-committed runoff. As a sequel to the Perspective Plan, the Master Plan for Artificial Recharge to Groundwater (CGWB, 2002) was prepared and approved by the Ministry of Water Resource on the basis of hydrogeological parameters and hydrological data available for each state. The identification of feasible areas for artificial recharge to groundwater was made on the basis of depth and declining trend of groundwater levels. The plan provides information about area specific artificial recharge techniques to augment the ground water storages based on the availability of source water and capability of subsurface formations to accommodate it. As a part of the Master Plan, a number of demonstration projects were implemented between 2007 and 2012 as mentioned in Table-2.

Table 1. Artificial recharge structures identified and recommended by CGWB for groundwater resources development purposes.

Lithology	Topography	Type of structure
Alluvial or hard rock	Plain area or gently undulating area	Spreading pond, subsurface dike, minor irrigation tank, check dam, percolation tank or unlined canal system
Hard rock down to 40 m depth	Valley slopes	Contour bunding or trenching
Hard Rock	Plateau regions	Recharge ponds
Alluvial or hard rock with confined aquifer to 40 m depth.	Plain or gently sloping of flood plains	Injection well or connector well
Hard rock	Foot hill zones	Farm ponds or recharge trenches
Hard rock or alluvium	Forested areas	Subsurface dikes

Table 2. List of Structures proposed under the Master Plan (CGWB, 2002) [Source : Saph Pani, 2012]

Area Identified for Artificial Recharge	448760 km^2
Volume of water to be recharged	36.5 km^3
In rural areas	225000
In urban areas (rooftop rainwater harvesting)	3700000
Total number of structures proposed	3,925,000
Total cost of structures proposed	245000 MINR
Check Dams/Cement Plug/Anicuts	110000
Recharge Shafts and Dug wells	48000
Gully Plugs /Gabion Structures	26000
Development of Springs	2700
Revival of Ponds/Tanks	1000

The common recharge techniques employed by CGWB are:

i) Flooding
ii) Recharge Basin or Percolation Tanks

iii) Gully Plug/Check Dam/Nala Bund/Gabbion Structures
iv) Recharge Wells / Dug Well Recharge/Borehole Flooding
v) Recharge Pits /Trench and Shafts
vi) Subsurface Dykes /Underground Bandharas
vii) Roof Top Rainwater Harvesting and Aquifer Recharge.

GENERAL EVALUATION OF MAR IMPLEMENTATION IN INDIA

Systematic application of MAR in India is still at an initial stage, and the concept of MAR in true sense is yet to gear up. What has been done and is going on is 'artificial recharge' for groundwater augmentation in depleted aquifers and dilution of groundwater quality concentration. As such, there is hardly any comprehensive investigation and performance evaluation of MAR underlining hydrology, hydrogeology, socio-economic and eco-system impact.

The CGWB evaluated the performance of 'artificial recharge structures' in different hydrogeological and meteorological contexts based on data from numerous pilot studies. The results were thoroughly documented. Benchmark performances (e.g. 75% percolation efficiency (CGWB, 2002) and suitability of structures for different contexts (CGWB, 2000) were published.

The impact of aquifer recharge in the area, on a watershed level and in India as a whole is dependent on the number of structures and their performance. No systematic inventory of structures exists, a figure of 0.5 Million is mentioned (Sakthivadivel, 2007).From the review of the case studies, it is seen that the scientific evidence for both positive and negative effects of MAR interventions is scarce. Data on the number, the performance and the effect of the structures would be necessary for future watershed management. Only by making use of evaluation aquifer recharge can be managed.

Evaluation of quantitative performance of recharge structures showed the changes over time. Monitoring of these changes forms the decision basis for the operation and maintenance plans. MAR structures need regular maintenance to ensure stable long-term performance, but this is often lacking (UNDP, 1987; Palanisami et al, 2006; Gale et al, 2006; Glendenning et al, 2012).

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Annexure - I

Traditional Rainwater Harvesting (RWH) and Groundwater Recharge structures usages in various places in India.

Name of structures	Place and State in which practises	Region	Features
Zing	Ladhak district in Jammu & Kashmir	Trans-Himalayan Region. Cold deserts.	Traditional water harvesting structure comprises of a small tank which collect melted glacier water through network of guiding channels.
Kul	Valleys of Himachal Pradesh, and Jammu & Kashmir	Western Himalayan Region. Precipitous mountains.	Traditional rainwater harvesting structure comprises of water channels which collect precipitated water from glaciers to village valleys.
Naula	Uttarakhand	Western Himalayan Region.	Traditional surface water harvesting structure comprises of small well or pond in which water is collected by making stone wall across a stream.
Khatri	Hamirpur, Kangra, and Mandi dist`ricts in Himachal Pradesh	Western Himalayan Region.	Traditional water harvesting structure of about 12 ft.x 10ft x 6 ft in size carve in hard rock mountain, in which rainwater is collected from roof through pipes or through seepage from through rocks.
Kuhl	Himachal Pradesh	Western Himalayan Region	Traditional irrigation system consists of headwall constructed across ravine for storage and diversion of flow through a canal to irrigation fields.
Apatani	Arunachal Pradesh, Sikkim & Darjeeling district in West Bengal.	Eastern Himalayan Region.	Traditional rainwater harvesting system for surface water conservation. In Apatani system, valleys are traced into plots separated by about 0.6 m high earthen dams. These plots are connected to one another by inlet and outlet arrangement located on opposite sides. The inlet of low lying plot acts as the outlet of the adjoining plot. Deeper channels connect the inlet point to the outlet point. Traced plot can be flooded or drained off by opening and blocking the inlets and outlets. Stream water tapped near forest hill slopes is conveyed to the agricultural fields through a channel network.

Zabo (Ruza system)	Nagaland	Northeaster Hill range	Traditional rainwater harvesting structure like pond in which runoff passes through terraces are collected in it for forestry, agriculture and animal care.
Bamboo Drip Irrigation	Meghalaya	Northeaster Hill range	About 200 years old traditional system. Bamboo pipes are used to divert perennial streams and springs at the hilltops to lower reaches by gravity for irrigation of plantations. The channel sections, which are made of bamboo, divert and convey to the plot site from where it is again distributed to branches.
Dongs	Assam	Brahmaputra Valley	Traditional artificial groundwater recharge system comprises of ponds, normally constructed for irrigation. These ponds receive water from surrounding hills.
Dungs and Jampois	Jalpaiguri in West Bengal	Brahmaputra Valley	Small irrigation channels which link rice fields to streams
Dighi	West Bengal	Indo-Gengatic plains	A square or circular reservoir with steps to enter. Each Dighi has its own catchment area and a sluice gate. People are not allowed to bathe and washed clothes on the steps of Dighi, however allowed to take water for personal use. Most of the houses had either their own wells or smaller dighis on their premises.
Kunds/ Kundis	Western Rajasthan & some areas in Gujarat	Thar Desert	Rainwater harvesting structures look like an unturned cup nestling in a saucer. Essentially a circular underground well in which rainwater is collected for drinking. The sides of the well pits are covered with lime and ash. Most of the pits have dome shaped cover or at least a lid to protect water. The depth and diameter of the kund depend on the requirement of water.
Kuis and Beris	Western Rajasthan	Thar Desert	Seepage collecting structures of 10-12 m deep pits dug near tanks. Kuis are also used to harvesting rainwater in areas of meagre rainfall. The mouth of a pit is usually made very narrow to prevent evaporation. Pit gets wider as it burrows under the ground to enable it seep into large surface area.
Baoris/Bers	Rajasthan	Thar Derest	Community wells collect rainwater for use to meet drinking water needs. Baoris can hold water for long time because of almost negligible evaporation.
Jhalaras	Rajasthan & Gujarat	Thar Desert	Man-made community tanks uses for religious rites. Often rectangular in shape and have steps from three or four sides. Jhalaras are groundwater bodies which collect subterranean seepage water of talab or lake located upstream and are built to ensure easy and regular supply of water for bathing and religious rites.

Nadis	Jodhpur, Rajasthan	Thar Desert	Village ponds used for storing water from adjoining natural catchment during rainy season. Sites for nadis are selected by villagers based on natural catchments and their yields.
Tobas	Rajasthan	Thar Desert	Natural ground depression in a catchment having low porosity uses for storing of surface water from rainy season.
Tankas	Bikaner in Rajasthan & Dwarka in Gujarat	Thar Desert	Small underground tanks generally circular in shape & lined with fine polish lime, built in the main house or courtyard to collect rainwater. These tanks' water are used for drinking
Khadin	Jaisalmer in Rajasthan	Thar Desert	A rainwater harvesting system on farmland designed storing surface runoff for agriculture. Its main feature is a long earthen embankment (100-300 m) across lower hill slopes.
Vay/ Vavdi/ Baoli/ Bavadi	Gujarat & Rajasthan	Thar Desert	These are step wells known by Vay or Vavdi in Gujarat and Baoli or Bavadi in Rajasthan. Practices of these types of step wells are found non-existence nowadays.
Virdas	Rann area of Kutch in Gujarat	Thar Desert	Shallow wells dug in low depression called Jheels (Tanks).. These structures harvest rainwater. The sites selection of these structures are made such a way that they separate freshwater from unpotable saltwater.
Talabs/Bh andis	Eastern Rajasthan & Bundelkhand in Madhya Pradesh	Central Highlands	Natural or man-made reservoirs. A reservoir area less than five bighas is called talai; a medium sized lake is called talab; bigger lakes are called sagar or samand. These reservoirs serve irrigation and drinking water requirements. When the water in the reservoir dries up just a few days after the monsoon, the reservoir beds are used for rice cultivation.
Saza Kuva	Aravalli hills in Marwar in Eastern Rajasthan	Central Highlands	An open well with multiple owners used for irrigation. It is constructed by digging soil and generally circular in shape.
Johads	Alwar district in Rajasthan	Central Highlands	Small earthen check dams that capture and conserve rainwater, improve percolation and groundwater recharge. It has successfully been used since 1984.
Rapat	Eastern Rajasthan	Central Highlands	Percolation tank with a bund by either masonry wall or earthen, to impound runoff from watershed. It is mainly used for groundwater recharge.
Katas/ Mundas/ Bandhas	Orissa & Madhya Pradesh	Eastern Highlands	These were ancient structures used for irrigation purposes. A kata is constructed north to south or east to west of a village by a strong earthen embankment curved at either end and is built on a drainage line to guide drainage water from upland to the irrigation field.

Cheruvu	Chitoor and Cuddapah districts in Andhra Pradesh	Deccan Plateau	Traditional water harvesting reservoirs to store runoff.
Kohlis	Bhandara district in Maharastra	Deccan Plateau	Traditional water tanks which hold rainwater for irrigation of sugarcane and paddy cultivation.
Bandharas	Maharastra	Deccan Plateau	Traditional stream/river water harvesting structures consist of check dams or diversion weirs constructed across streams/rivers to raise water level in the streams/rivers for diversion of water to irrigation fields. Most of the Bandharas are defunct today.
Kere	Central Karnataka	Deccan Plateau	Tanks traditionally used for supply of irrigation water. These tanks are fed either by channels branching off from anicuts (check dams) built across streams or by streams in valleys.
Ramtek model	Maharastra	Deccan Plateau	Surface water runoff harvesting tanks connected in series to catch rainwater from watersheds and supported by high yielding wells and structures like baories, kunds.. The tank located at the upper reaches close to hills are filled up, water flows to downstream to successive tanks through interconnecting channels. This sequential arrangement generally ends to a small watershed to store the remaining water.
Surangam	Karnataka	Western Ghats	Surangam (means tunnel) is a horizontal well mostly excavated in hard laterite rock formations. The excavation is done to a depth till a good amount of water is struck. Underground water seeps out of the hard rock and flows out of the tunnel. This water is collected in an open pit constructed outside a surangam.
Korambu	Kasargod and Thrissur districts in Kerala	Eastern Ghats	Korambu is a temporary dam constructed across mouth of channels by brushwood, mud and grass. It is used to raise water level in the canal and to divert the water into field channels. It is designed in such a way that required quantity can flow to the diversion channel and excess water can overflow through it. Water is allowed to flow from one field to another until all fields are irrigated.
Eris	Tamilnadu	Eastern Coastal Plains	Eris (tanks) are very common in irrigated area of Tamilnadu. They play several important roles: maintaining ecological harmony, preventing soil erosion and wastage of surface runoff, and recharging groundwater in the surrounding areas.