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WATER STORAGE IN RESERVOIRS AND AQUIFERS: RECHARGING GROUND WATER

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ABSTRACT

Average per capita water availability in India as on 2011 is only 1543 cu.m. which is far below that in USSR (19,500), USA (9,900) and China (5,000). Principal source of India's water resources is monsoon rainfall which varies from place to place, year to year and lasts for only 3 to 4 months in a year. While some parts of our country are devastated by floods, some others suffer from acute droughts. Solution lies in water storage and transfer of water from surplus to scarce basins. Storage of flood water in surface reservoirs and underground aquifers is necessary for fighting recurring floods and droughts in India. Excess flood waters should be transferred to drought prone areas by interlinking rivers. Re-use, recycling and recharging of waste and sewage water after proper treatment will be highly beneficial not only in water conservation but also in prevention of river and ground water pollution. Artificial recharge of ground water will be beneficial both for water conservation and sustainability of ground water supply to meet increasing demand for domestic and agricultural use, especially in rural and semi- urban areas. All these issues have been discussed in the paper at length.

Key words: *Storage, Water transfer, Water Pollution, Ground water, Artificial Recharge*

INTRODUCTION

In 1947 when India woke to freedom, the country was facing stark realties of recurring famines and floods. There were hardly any moisture conservation or watershed programs or any storage to meet the demands for domestic use, irrigation, industries and hydro-power generation. Based on limited experience and inadequate technological strengths, the country embarked on its journey into water world of the future. Several multi- purpose river valley projects like DVC, Bhakra-Nagal, Nagarjunsagar etc. were completed. A water mission has now been appointed to explore pathways and future option to reduce emerging water stress and to meet increased marketing demands and chain management of agricultural produce like food, edible oil, pulses etc.; soil health, use of good seeds, organic farming and GM crops etc. are also included in the agenda. No natural resource, including water and land, are inexhaustible and any overuse can cause adverse and non - reversible or permanent impacts. Pollution of water is imposing high cost on health and treatment for reuse and recycling. Civilizations decay when structural interventions of policy, pricing or inputs and outputs and the unchecked misuse, is not sustainable.

The population of India in 2025 is being projected as 1394 million, when average per capita availability of water will fall to just 1340 m^3 in an average year. Current trends on high quantum of withdrawals of sub-surface waters from the underground aquifers pose a veritable threat and challenges. The earlier concepts had implied reducing water losses in conveyance of irrigation canals, increasing the operational efficiency in distribution at minimal cost. Storages were built in upper reaches in mountains or in downstream rocky terrains for subsequent releases /abstractions; the current search is for innovative techniques to increase conservation, water harvesting and increased artificial recharge of ground water. Water savings, treatment and reuse techniques continue to be on priority lists in urban cities and process industries.

Water conservation is a continuous and imperative infrastructural need for a large country like India, with extensive tracts of arable lands, where rainfall clouds from monsoon trade winds are received, albeit with uncertainties in their timings and for just three to four months in a year. The snow contribution in the surface water flows is limited; sea water is still considered expensive to reclaim; the rate of pollutants in inflows on land and waters surfaces is experiencing a rapid increase and ingress due to high demand and release of waste waters due to rapid urbanization and industrialization.

The sustainable water world, with India as part of global community, is expected to address at least three essential dimensions, namely, removal of poverty, economic development and conservation of ecosystems for a sustainable life for coming generations. The critical developmental challenges for water, now emerging, are its potable supplies, sanitation and hygiene, increasing urbanisation and food security. Water is required for generating more energy industry and employment. Post-2015 development agenda does not have specific targets listed in the Millennium Development Goals. Monitoring and making water available, it's judicious use, water conservation and related impacts, quantity and quality of water available, possible security thrusts and risks on fetching and transporting water and their costs are of prime concern.

As per the report of the National Commission on Integrated Water Resources Development (NCIWRD-1999), India has roughly 4% of the world's fresh water resources to feed its 17% world population. India receives an average precipitation of about 1170 mm which corresponds to an amount of annual volume of 4000 BCM. There is considerable variation in precipitation both in time and

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space. Nearly 75% of precipitation i.e. 3000 BCM occurs during the monsoon season confined to 3 to 4 months (June to September) in a year. Figures-1 and 2 depict the water crisis in India due to rise in population over the years.Table-1 gives the per capita water availability of some of the countries in the world as on 2011.

Fig 1: Showing Water Crisis in World

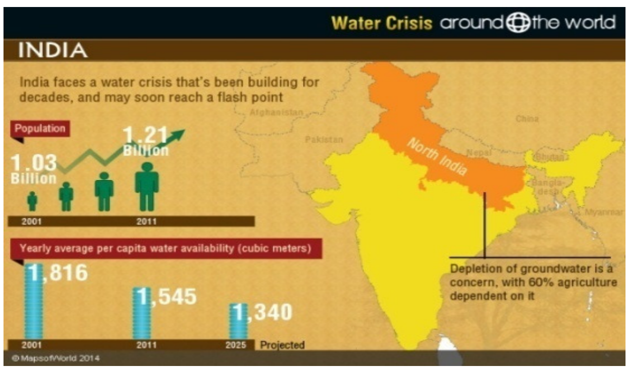

Fig 2: Growth of population and per capita availability of Water in India

Table-1: Per Capita Availability of Water in Different countries in The World (as on 2011)

USSR	USA	China	Australia	India	Ethiopia
19500	9900	5000	2420	1545	250

As the population increases, displacement and resettlement of project affected population, caused by submergence of land for storage, becomes a contested issue, make the choice of dam reservoir - technology unpopular . Focus turns to footprints of ecology and. rejuvenation of river flows and its water quality. Need for adaptation to climate resilience, conservation of water in conveyance and distraction at end use points can sway the tide back to storages on surface and the under ground aquifers. Areas with water availability less than 1000m^3 per capita per year are designated as scarcity areas. Although, the average figure (1545), for India [Iyer,1989] if taken as a whole, indicates that India may not be water deficit, but looked from the spatial distribution of water from basin to basin, there is a great deal of non-uniformity due primarily to extreme non-uniform rainfall distribution. Table-2 gives the list of surplus and scarce basins in India (IWRS, 2007). Moreover, the rapid rise in population growth in India will soon render many of the surplus basins in India to be water scarce basins. Objective of writing this paper is to focus on necessity of more storage -both surface and underground- for water conservation, water transfer from surplus to scarce basins and sustainable development of water resources in India.

Table2: Surplus and Scarce Basins in India

SurplusBasins		ScarceBasins	
Basins	**Per Capita Availability in m^3 Per Year**	**Basins**	**Per Capita Availability in m^3 Per Year**
Brahmaputra Basin	18,417	Eastflowing Rivers between Mahanadiand Pennar	919
Barak Basin	7,646	Cauvery	666
West flowing Rivers between Tadri and Kanyakumari	3,538	Pennar	648
East flowing Rivers between Tapi and Tadri	3,194	West flowing River Basin of Kutch and Saurashtra including Luni	631
Narmada	2,855		
Brahmani-Baitarni	2,696		
Mahanadi	2,546	East flowing River Basins between Pennar and Kanyakurnari	383
Godavari	2,026		
Indus	1,757		
Ganga	1,473		

WATER DEMAND AND AVAILABILITY OF WATER

Estimated demand of water for different sectors from 2010 to 2050 is given in Table-3 (INAE,2008). Irrigation consumption is the highest- varying from 78% in 2010 to 68% in 2050. With time and rise in population, demand pattern is changing as more water has to be diverted to meet the need of different sectors other than irrigation which currently wastes a lot of water (Mazumder,1984) mainly due to heavily subsidized/free water supply policy.

As per the assessment done by CWC (1993), the average annual water availability is 1869 billion cubic meters (BCM) from different river basins in the country (Table-4). The utilizable water with conventional approach is 1121 BCM which comprises of 690 BCM of surface water and 431 BCM of replenishable ground water. The remaining water i.e. 748 BCM is lost to the atmosphere through evapo-transpiration from rainfed agriculture, barren lands, forests, natural vegetation, natural ponds and lakes etc.

Table-3: Water Demand for Different Uses

Sl.No.	Total Water Requirement for Different Uses (in BCM)			
	Uses	Year 2010	Year 2025	Year 2050
		High Demand scenario	High Demand scenario	High Demand scenario
1.	Irrigation	557	611	807
2.	Municipal	43	62	111
3.	Industries	37	67	81
4.	Power (Energy)	19	33	70
5.	Others	54	70	111
	Total	**710**	**843**	**1180**

Table-4: Potential and Utilizable Surface and Ground Water Resources and storages in Different River Basins in India

S. No.	River Basin	Catchment area (Sq.Km)	Average Water Resources Potential (BCM)	UtilisableWater Resources (BCM)			
				Surface	Ground	Total	Storage (BCM)
1	2	3	4	5	6	7	8
1	Indus	321289	73.3	46	26.49	72.49	16.3232
2	Ganga-Brahmaputra Meghna						
	(a) Ganga	861452	525	250	.170.99	420.99	56.326
	(b) Brahmaputra	194413	537.2	24	26.55	50.55	2.5131
	(c) Barak & others	41723	48.4	-----	------	----	9.891
3	Godavari	312812	110.5	76.3	40.65	116.95	43.4442
4	Krishna	258948	78.1	58	26.41	84.41	54.807
5	Cauvery	81155	21.4	19	18.22	18.22	9.098
6	Subernarekha	29196	12.4	6.8	-----	6.8	2.459
7	Brahmani-Baitarni	51822	28.5	18.3	------	18.3	6.218
8	Mahanadi	141589	66.9	50	16.48	66.48	14.4673
9	Pennar	55213	6.3	6.9	------	6.9	5.079
10	Mahi	34842	11	3.1	------	3.1	5.167
11	Sabarmati	21674	3.8	1.9	------	1.9	1.686
12	Narmada	98796	45.6	34.5	10.83	45.33	24.4567
13	Tapi	65145	14.9	14.5	8.27	22.77	10.605
14	West Flowing Rivers from Tapi to Tadri	55940	87.4	11.9	17.69	29.56	17.098
15	West Flowing Riversfrom Tadri to Kanyakumari	56177	113.5	24.3	18.84	43.14	12.4393

16	East Flowing Rivers between Mahanadi and Pennar	86643	22.5	13.1	------	13.1	3.857
17	East Flowing Rivers between Pennar &Kanyakumari	100139	16.5	16.5	-------	16.5	1.456
18	West Flowing Riversof Kutch and Saurashtra including Luni	321851	15.1	15	-------	1.5	6.847
19	Area of Inland Drainage in Rajasthan	—	Negl.			-----	------
20	Minor Rivers draining into Myanmar (Burma) and Bangladesh	36302	31	------	------	-------	-----
	Total		**1,869.4**	**690**	**431.44**	**1121.44**	**304.348**

WATER STORAGE &WATER TRANSFER

Only way India can overcome the problems of water scarcity and drought situations is to store water- both surface and underground- as well as by transfer of water from surplus basins to scarce basins. These are briefly discussed below.

Storage Requirement

The National Water Policy (2012) recommends that the anticipated increase in variability in availability of water because of climate change should be dealt with by increasing water storage in its various forms namely, small/medium/large reservoirs, ponds, storage as soil moisture, ground water. States should be incentivized to increase water storage capacity, which inter-alia should include revival of traditional water harvesting structures and water bodies. The National Water Policy further recommends that all water resources projects including hydro power projects, should be planned to the extent feasible as multi-purpose projects with storage provision to derive maximum benefit from available topology and water resources. Even after constructing 4,525 storage structures, 9 out of 10 river basins with a population of 200 million are currently facing acute water shortage .The need for increasing storage in India is obvious if we look into country-wise scenario given in Table-3. Even after all the proposed storage structures are constructed in India (Table-5), per capita storage available may touch the figure 400 m^3only.

Owing to topographic, hydrologic and other constraints, live storage capacity built so far in the different basins is only 305 BCM (Table-4) which corresponds to 33.88% of the utilizable water resources and 23% of the potential water resources. It is apparent that the existing surface storage capacity is meager to fight drought like situations arising occasionally in different parts of India. Moreover, loss of live storage due to silting of reservoir is estimated as 53 BCM by 2050. There are only a few storage reservoirs like Bhakra which can hold flood waters in high rainfall years to fight consecutive drought years due to scanty rainfall.

Depletion of ground water is already causing concerns and the natural recharge can not meet the sustainability requirements of the present level of ground water usage. It is, therefore, required that we increase our reliance mostly on surface water resources and artificial recharge of ground water for our future need. Creation of storage of water is not limited to defining the quantities/ capacities alone. It is also dependent upon the topography, geotechnical conditions and the land availability. Each of this ingredient is not available in plenty nor are they uniformly distributed so as to enable us to create storages at will and wherever we like to have them. Optimizing the land requirements is an important aspect of the storage planning. Though much reviled, large storages require lesser land foot print for storing relatively larger amount of water and are also efficient in conserving the storage throughout the year by way of lesser evaporation from a deeper water body. Direct evaporation of water stored in aquifers is nil.

Water Transfer by Interlinking of Rivers

Optimum use of water through adoption of proper technology in rain water harvesting, improving water use efficiency (Mazumder,2015), using pressurized water distribution are becoming unavoidable because of wide variation of rainfall and water availability (table-2) in different regions of India, Govt. of India has drawn a perspective plan to interlink Indian rivers (Fig.3) by constructing 30 link canals-14 in Himalayan and 16 in Peninsular regions in India (NWDA,2005). Govt. of India has already implemented few short links for transfer of water from surplus to deficit areas (Mazumder, 2006)**.**

Planning for Storage

Surface Storage

Resilience of water shortage, adaptation during climate change and access to districts which are drought prone or even attracting private sector investment and participation, can be built in form of more and more carryover storages with access provided to inaccessible areas using pipeline grids .The new strategy can see the country through the anticipated difficult periods of the shortfalls. As an example, average reservoir storage position in 2013 has enabled us to tide over the crisis of late arrival of adequate rains in 2014. Areas around foothills are the ideal locations since they provide the necessary depths of reservoirs and are located at the head of the agricultural and urban hubs located in plains. The transfer of the water can take place through gravity removing the necessity of energy for pumping. To address the concern, GOI has recently planned additional storage schemes and interlinking grids, as shown in Table-5.

Sub-Surface storage

India is the largest consumer of ground water in the world with an estimated abstraction figure of 230 BCM per year. About 60 % of the quantum is in use for irrigation. About 80 % of demand of water for domestic use particularly for rural water supply is being met by ground water. Of the total replenishable 431 BCM of ground water, 369.6 BCM is available for irrigation. About 71 BCM is estimated to be available for domestic, industrial and other uses. Central Ground Water

Board, the apex organisation is developing databases on the ground water flow systems and ground water availability in each hydro - geological settings. Aquifer mapping is in progress and wells are being drilled to achieve the objectives. Sustainable ground water for each aquifer is

being drawn. Power feeders are being separated from agricultural feeders. Ground water storage and pumping have greater flexibility and better efficiency compared to surface storage.

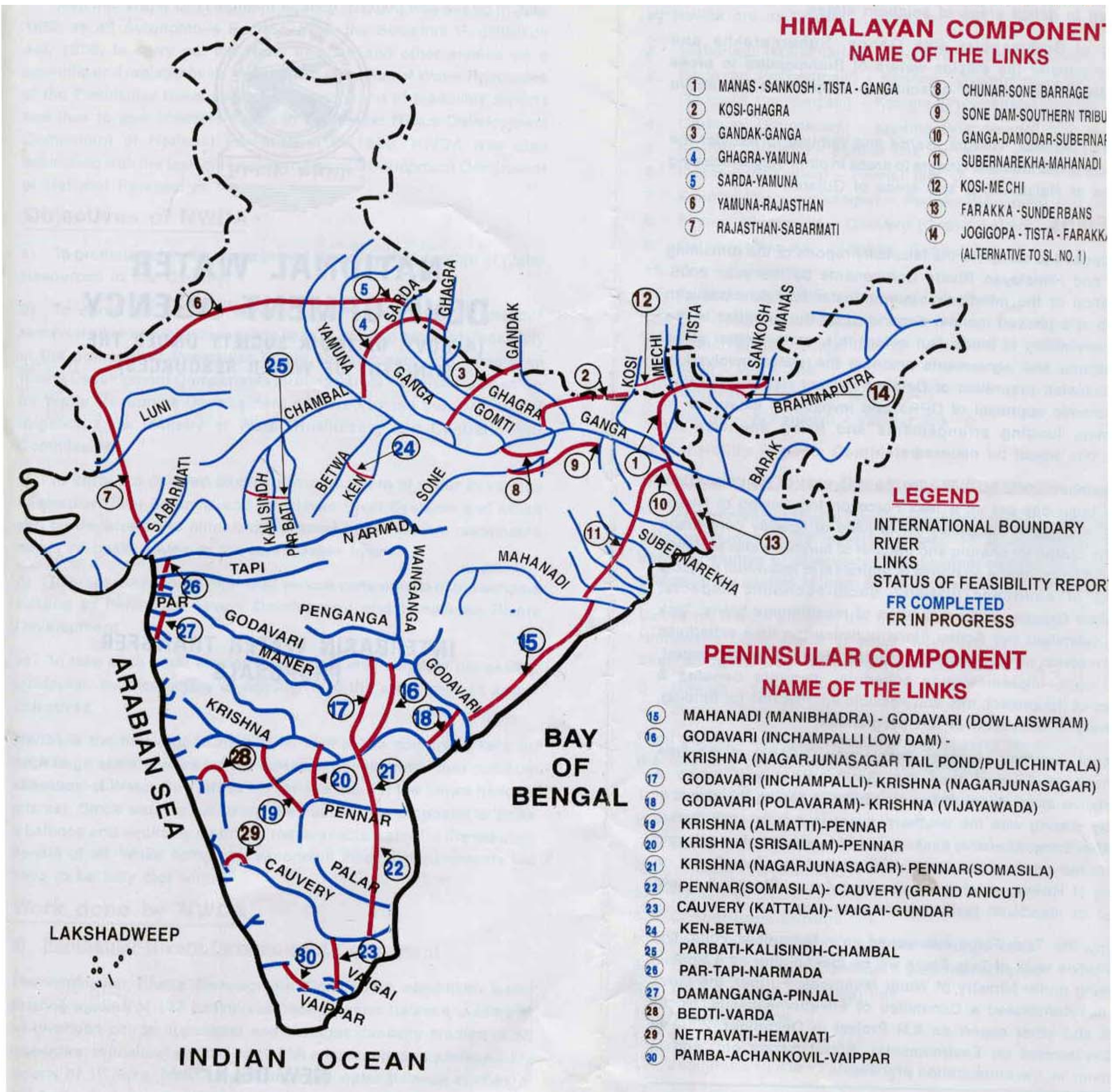

Fig.3: Interlinking of Rivers in India (Under Perspective Plan by NWDA

Table-5: Proposed New Projects to Augment Storages In India

(A)Ongoing National Projects

Sl. No.	Name of the Project	State	Storage (MCM)
1	Gosikhurd	Maharashtra	1,147.06
2	ShahpurKandi	Punjab	14.80

(B)National Projects under Appraisal

1.	Renuka	HP	542.70
2.	LakhwarVyasi	Uttarakhand	400.86
3.	Kishau	HP/ Uttarakhand	1,282.74
4	Ken Betwa	Madhya Pradesh	2,775.15
5.	Ujh multipurpose project	J&K	814.04

(C) National Project under DPR Preparation Stage

1.	Bursar	J&K	1,233.40
2.	Gyspa project	HP	740.04
3.	Kulsi Dam Project	Assam	345.35
4.	Noa-Dehang Dam Project	Arunanchal Pradesh	320.68

(D) National Project under Conceptual Stage

1.	Upper Siang	Arunanchal Pradesh	21,584.50

(E) Project recently included

1.	Indira Sagar Pollavaram	Andhra Pradesh	2,129.00

DATA COLLECTION BY CWC & CGWB

A committee constituted under Director (WM), CWC, had carried out reassessment of live storage capacity of reservoirs in the country during 2011. As per reassessment, live storage capacity of completed dams is 304 BCM (table-4), the live storage capacity of proposed new reservoirs (Table-5) is 30 BCM. India has a total geographical area of 329 Mha having an annual precipitation of 4000 BCM with wide temporal and spatial variation. From river basin point of view, the country has been divided into 26 river basins. The collection of hydro-meteorological data for all the river basins in a scientific manner is essential for various uses viz. planning and development of water resources projects, climate change studies, water availabilitiy studies, flood/inflow forecasting, solving of international & inter-state issues, morphological studies, inland waterway development, reservoir simulation studies, other water research related activities. These activities are carried out by central water commission (CWC), an attached office of ministry of Jal Shakti under the department of water resources, river development and Ganga rejuvenation. At present, CWC is operating a network of 954 hydrological observation stations (including 76 exclusive meteorological observation stations) in different river basins of the country to collect (i) Water Level (gauge), (ii) Discharge, (iii) Water Quality and (iv) Silt, along with selected metrological parameters including snow observations at 27 key stations. The hydrological data collected by CWC from sites are scrutinized, validated and published in the form of water year book, water quality year book and sediment year book. During the year 2013-14, hydro-meteorological data from all 954 sites have been observed and few sites had been upgraded with modern hydrological equipment such as Acoustic Doppler Current Profiler (ADCP). Water quality monitoring has been strengthened by providing sophisticated water quality analysis equipments in the laboratories. Also, monitoring of glacial lakes/water bodies in Himalayan region have been undertaken and model for snowmelt runoff forecasting has been developed through collaboration of National Remote Sensing Center (NRSC), Hyderabad.

WATER CONSERVATION

Water conservation does not mean only storage of water but also preservation of water by reducing consumption, recycling and reuse of waste water through proper management as briefly discussed below.

Transition Needed From Resource Development to Management Mode

Water saving irrigation research - such as alternate wet and dry irrigation for rice or the system of rice intensification - can help reduce water consumption. 50% to 60% of water supplied for irrigation is lost mainly due to lack of proper management (Mazumder,2015). In the developed countries, pricing of water and electricity offer powerful levers for agricultural demand management for surface and groundwater. The country's groundwater economy has boomed by bleeding the energy economy. With electricity industry getting close to bankruptcy, there are growing demands for eliminating power subsidies; but governments find it unable to do so because of stiff opposition from farmers lobby. Recent IWMI research (Shah et al 2004) has argued that sustaining a prosperous groundwater economy with viable power sector is feasible; but it requires that the decision makers in the two sectors jointly explore superior options for energy-groundwater co-management.

IWMI(2003) studies recognize that switching to volumetric water and electricity pricing may not be politically feasible at present. However, they advocate flat tariff accompanied by sophisticated management of high quality but carefully rationed water and power supply to maintain the financial sustainability of water and energy use in agriculture and the environmental sustainability. Such a strategy can curtail wasteful use of surface and groundwater in irrigation to a large extent. Use of surface and ground water irrigation on private initiative will reduce water logging, which otherwise would have required massive public investment in drainage and salinity management. Pump irrigation farmers apply less water per hectare, achieve higher ratio of evapo-transpiration to consumptive fraction, and obtain higher yields/ha as compared to surface flow irrigation by canals. In dry-land areas, supplemental pump irrigation has a dramatic impact of stabilizing rain-fed yields and promote agrarian diversification (Giordano, M. and Villhoth, K.G. (2007).

Abatement of Water Pollution

Both surface and sub-surface water available in India are getting increasingly polluted with rise in population over time. Such polluted water is unfit for any use - be it domestic, agriculture or industry. Highest priority should be laid on abatement of water pollution for survival of mankind, animals, flora and fauna and for preserving eco system. Conservation of water means not only quantity but quality of water too.

River Pollution

River water is the principal source of water to meet various demands of the society. All civilizations are built around rivers. Most of the rivers are getting polluted day by day, principally due to discharge of waste water and sewage in to the rivers. Although Govt. of India has promulgated several acts to control river pollution, there is hardly any implementation of these acts due to an unholy nexus between water inspectors and industries and indifference of municipal authorities. Govt. of India is spending huge amount of money every year under 'Swatch Bharat Abhiyan' which includes cleaning of river water; but the results are not up to expectation due to corruption and inefficiency as well as lack of proper technology in water sector.

Ground Water Pollution

Ground water, which is the principal source of drinking water and agriculture in the rural areas, is also getting polluted with time. Over use of ground water and consequent fall in water table has not only increased draft and pumping cost but also pollution of ground water from arsenic, heavy metals and other harmful salts. Heavy pumping in coastal areas is responsible for sea water intrusion in aquifers. Solid wastes in cities dumped over ground is responsible for ground water pollution due to leaching and subsequent infiltration of highly toxic water in to the ground.

Recycling and Re-Use of Water

In a push to the 'Swachh Bharat' campaign, Govt. of India is putting a lot of emphasis for recycling and re-use of water. It allows distribution companies to buy any amount of power produced from wastes. Further, the power plants will have to compulsorily use processed municipal waste water available in their vicinity. The proposed tariff policy is aimed to provide incentives to renewable energy projects as well as efficient use of resources by power generation plants based on conventional sources of energy like coal-based thermal projects.

Waste Water and Sewage Treatment

With a view to treat and reuse waste waters, union finance ministry has approved joint water supply and sewage treatment projects with international funding agencies. For example, Pune Municipal Corporation will take up these works in association with the Japan International Cooperation Agency (JICA.). The project titled `Pollution Abatement of River Mula-Mutha in Pune', will be the city's biggest sewage treatment and river restoration project. The total cost of the project is USD 154 million (INR 990.26 crore), of which 85% (about USD 129 million or INR 841.72 crore) will be contributed by the Union government. The civic body will raise the remaining 15%.

Community Aquifer Management:

In evolving groundwater governance regimes, India should adopt the US experience of tradable water rights and groundwater management districts (Shah et.al, 2004). The underlying premise is that if groundwater users are organized around aquifers for self-governance, they will internalize third-party externalities through bargaining and negotiation, collectively monitor the behavior of groundwater as well as its abstracters and ensure the long term sustainability of both. A more practical consideration is to use groundwater associations as agents in monitoring and enforcement of government policies and laws. The idea of groundwater organizations has a wide appeal; it was advocated to India by a British Geological Survey study (BGS, 2004). In south India, FAO supports Andhra pradesh farmer-managed groundwater systems. These bodies are vested with the power to grant permits for groundwater use, declare an aquifer as overexploited, and formulate an aquifer management plan for its recovery and replenishment.

GROUND WATER REPLENISHMENT

In some coastal plains along with arid alluvial plains facing overdraft of ground water, the central ground water board (CGWB) is taking measures against salinization and depletion of water table (Vaidyanathan.,1996) - a chronic form already visible in some parts of the country. It may seal the fate of agriculture and human settlement itself. Hard rock areas of peninsular India, where tube well irrigation expansion is way out of proportion to the limited storage offered by aquifers, resource depletion is a serious issue in itself. It has also. aided growing concentration of fluoride and other salts in ground water which is the main source of drinking water supply for both rural as well as urban population. Problem of geogenic contamination of groundwater -such as with arsenic in eastern Ganga basin and fluoride in western and peninsular India - are large and serious. The causal role of pump irrigation in mobilizing fluoride and other salts in groundwater is clearer than in arsenic contamination whose chemistry is still tenuous and disputed. Alarmingly, a quarter of India's food harvest is at risk if India fails to manage her groundwater properly. If India does not take immediate charge of her groundwater, its agricultural economy may crash.

Artificial Recharging Ground Water

To improve the ground water situation, it is necessary to recharge -naturally and/or artificially- the depleted ground water aquifers. Artificial recharge is the process by which the ground water is augmented at a rate much higher than those under natural condition of replenishment. Groundwater supports more than 55% of our irrigation requirements, 85% of domestic requirements in rural areas and over 50% of requirements in urban and industrial uses in the country. Ground water storage that could feasibly be exploited has been estimated as 214 BCM of which 160 BCM is considered retrievable. A conceptual plan for artificial recharge of ground water for the country has been prepared by CGWB (2011) . Out of total geographical area of 32,87,263 sq. km. of the country, an area of 4, 48,760 sq. km. has been identified suitable for artificial recharge. The total quantity of surplus monsoon runoff (flood water) to be used for recharging works out as 36.4 BCM. During the Xth Plan, demonstrative studies on artificial recharge of ground water and rain water harvesting have been taken up by CGWB in 8 districts in Andhra Pradesh, Madhya Pradesh, Karnataka and Tamil Nadu at a total cost of Rs. 595 crores (ADB, 2014). The constructions of 189 artificial recharge structures out of 200 have been completed and remaining are under construction. The impact assessment studies of the completed recharge projects are being conducted by CGWB. During the XIth Plan, state agencies in coordination with CGWB are conducting studies for feasible areas, structures and other modalities for artificial recharge projects. The detailed project reports for artificial recharge received from Tamil Nadu, Punjab, Kerala, Andhra Pradesh and Arunachal Pradesh are under consideration (World Bank, 2000).

The available techniques are easy, cost-effective and sustainable in the long term. Many of these can be adopted by the individuals and village communities with locally available materials and manpower. There are so many methods or techniques of artificial recharge of ground water. Depending upon the area and source of water, particular technique can be used for the recharge. Hydro/Irrigation projects also help in the ground water recharge. Storage basins and hydro/Irrigation projects rapidly improve the ground water level.

Identification of Areas for Recharge

The areas suitable for recharge are identified on the following basis:

(i) Where ground water level is lowering due to excessive use of ground water for domestic, industrial and agricultural purposes
(ii) Where substantial part of the aquifer has already been de-saturated i.e. regeneration of water in wells and hand pumps is slow after some water has been drawn.
(iii) In the lean season, availability of water from wells and hand pumps is inadequate.
(iv) Lack of other source of water and ground water quality is poor.

Sources of Water for Recharge

Following are the main sources which need to be identified and assessed for adequacy:

(i) Hydropower/irrigation project reservoirs from which water can be made available for recharge
(ii) Precipitation (rainfall) over the demarcated area
(iii) Large roof areas from where rainwater can be collected and diverted for recharge
(iv) Natural streams from which surplus water can be diverted for recharge, without violating the rights of other users
(v) Properly treated municipal and industrial waste waters. This water should be used only after ascertaining its quality to avoid aquifer contamination

Planning of Artificial Recharge

Inputs in the form of several studies e.g. (i) Hydro-meteorological studies, (ii) Hydrological studies, (iii) Soil infiltration studies, (iv) Hydro-geological studies (v) Geophysical studies, (vi) Chemical quality of water source etc. are vitally needed for execution of ground water recharge schemes. Details are available in text books on ground water (Todd, 1959).

Direct Techniques of Artificial Recharge

The techniques of artificial recharge can be broadly categorized as direct and indirect techniques. Direct techniques include:

- Flooding
- Basins or percolation tanks
- Stream Augmentation
- Ditch and furrow system
- *Over irrigation:*

Details of the above techniques are available in the Text Books (Todd,1959 ; Raghunath,2007).

Indirect Recharging Techniques

These include the following:

- Bore hole flooding
- Well Recharge
- Injection well recharge
- Natural openings cavity fillings
- Induced recharge from surface water source
- Aqifer modification

Details of techniques are available in the text boks (Chaturvedi,1985; Raghunath,2007; Todd,1959)

Role of Hydro Power/Irrigation Projects in Artificial Recharge

In the hydro power/irrigation projects, the water can be diverted from the river in to the tunnel/ canal for the purpose of recharge. As diversion structure, barrage or dam may be constructed across the river. In the upstream, reservoir is created for increasing the head and infiltration. The stored water in the reservoirs may be used for artificial recharge of the ground water. It is important for various hydro-power and irrigation projects, assessment of ground water resource, pollution and artificial recharge studies.

The water table is not horizontal in general and has high and low point in it i.e. it is not in equilibrium. In order that the equilibrium is approached, water moves inside the ground from the high points on the ground water table to the points lower down. The rate at which such movement occurs depends upon availability of the porous media to pass water through it and the driving force or hydraulic gradient. Hydraulic gradient depend upon difference in elevation and length. Due to head created by the reservoir, water will move from higher water level (reservoir) to the lower water level in both confined and unconfined aquifers. Key factors in the design and management of successful artificial recharge systems by creating the reservoir are:

(i) Site and system selection
(ii) Maintenance of adequate infiltration rates
(iii) Hydraulic continuity between the recharge system and the area of aquifer and
(iv) Effective ground water recovery.

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