GROUND WATER DEVELOPMENT AND MANAGEMENT STRATEGIES IN INDIA

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Introduction

Ground water resources play a vital role in sustaining the livelihoods of many countries in the world. Its ubiquitous occurrence, reliability and availability in all seasons have made it the primary buffer against drought, playing a pivotal role in ensuring the food security at all levels. More than half the world's population is considered to depend on ground water for its survival (UNESCO, 1992). The alarming depletion of ground water resources in the last few decades has made it the focus of attention of administrators, planners and policy makers all over the world, making it one of the most hotly discussed topics today.

Ground water has an important role in meeting the water requirements of agriculture, industrial and domestic sectors in India. Its importance as a precious natural resource in the Indian context can be gauged from the fact that more than 85 percent of India's rural domestic water requirements, 50 percent of its urban water requirements and more than 50 percent of its irrigation requirements are being met from ground water resources. The increasing dependence on ground water as a reliable source of water has resulted in its large-scale and often indiscriminate development in various parts of the country without due regard to the recharging of aquifers and other environmental factors. The unplanned and unscientific development of ground water resources, mostly driven by individual initiatives, has led to an increasing stress on the available resources. The adverse impacts can be observed in the form of long-term decline of ground water levels, de-saturation of aquifer zones, increased energy consumption for lifting water from progressively deeper levels and quality deterioration due to saline water intrusion in coastal areas in different parts of the country. On the other hand, there are areas in the country, where ground water development is still low-key in spite of the availability of sufficient resources. The canal command areas suffer from problems of water logging and soil salinity due to the gradual rise in ground water levels.

In view of the factors mentioned above, there is a need for strategies aimed at scientific and sustainable management of the available ground water resources in the country to avert the looming water crisis. Such a management strategy should consider various aspects such as the availability of ground water resources and their development prospects. These are described in the following sections.

Hydrogeological Setup

India is a vast country with a highly diversified hydrogeologic set-up. The ground water behaviour in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations with considerable lithological and chronological variations, complex tectonic framework, climatological dissimilarities and various hydrochemical conditions. Studies carried out over the years have revealed that aquifer groups in alluvial / soft rocks often transcend the surface basin boundaries. Broadly two group of water bearing rock formations have been identified depending on characteristically different hydraulics properties, viz. Porous formations which can be further classified into unconsolidated and semi consolidated formations

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having primary porosity and Fissured formations or Consolidated formations which have mostly secondary or derived porosity (Fig-1).

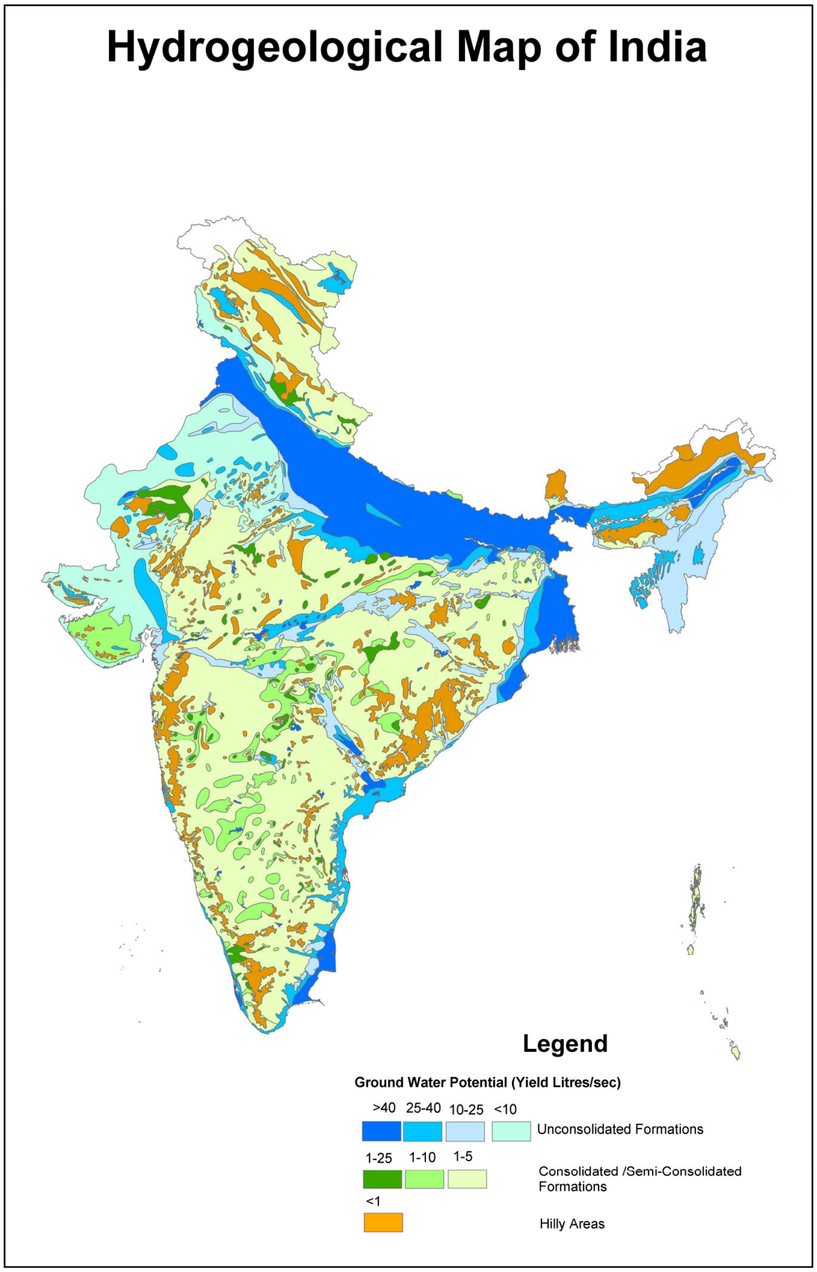

Fig. 1: Hydrogeological Map of India.

Physiographic and geomorphologic set up plays a vital role in the occurrence and distribution of ground water. An attempt has been made to establish broad relationships between different physiographic units and occurrence and movement of ground water. The entire country has been broadly divided into five distinct regions considering the characteristic physiographic features as well as occurrence and distribution of ground water.

i) *Northern Mountainous Terrain and Hilly areas*: The highly rugged mountainous terrain in the Himalayan region in the northern part of the country, extending from Kashmir to Arunachal Pradesh, is characterized by steep slopes and high runoff. This region is occupied by varied rock types including granites, slate, sandstone and limestone ranging in age from Paleozoic to Cenozoic. The yield potential of valley fills ranges from 1 to 40 lps. Though this area offers very little scope for ground water storage, the valley fills function as underflow conduit and act as the major source of recharge for the vast Indo-Gangetic and Brahmaputra alluvial plains.

ii) *Indo-Gangetic-Brahmaputra Alluvial Plains*: This region encompasses an area of about 850,000 sq km covering states of Punjab, Haryana, Uttar Pradesh, Bihar, Assam and West Bengal, , which is more than one fourth of country's area and comprises the vast plains of Ganges and Brahmaputra rivers underlain by thick pile of sediments of Tertiary and Qarternary age. The sediments have been deposited in a foredeep or crustal down –buckle. The thickness of the sediments decreases from north to south. At places the thickness of the alluvium exceeds 1000 m. This vast and thick alluvial fill form the most potential and productive ground water reservoir in the country. These are characterized by regionally extensive and highly productive multi-aquifer systems. In the present scenario, ground water development in this region is low key except the western most part in the states of Haryana and Punjab. The deeper aquifers available in these areas offer good scope for further exploitation of ground water with suitable measures. In Indo-Gangetic- Brahmaputra plain, the deeper wells have yields ranging from 25-50 lps.

iii) *Peninsular Shield Areas*: These are located south of Indo-Gangetic-Brahmaputra plains and consist mostly of consolidated sedimentary rocks, Deccan Trap basalts and crystalline rocks in the states of Karnataka, Maharashtra, M.P, Kerala and Tamil Nadu. Occurrence and movement of ground water in these formations are restricted to weathered residuum and interconnected fractures at deeper levels and they have limited ground water potential. The rocks are commonly weathered to a depth of 30 m under the tropical conditions in central and southern part of the peninsular region. Ground water occurs mainly in the weathered and fractured zones of rocks, within depth of less than 50 m, occasionally down to 100 m, and rarely below this depth. Locally deep circulation of ground water is indicated, as instanced by striking solution cavities or deeper water bearing fractures. Ground water development is largely through dug wells. The valley fills in this region are often dependable sources of water supply. The yield of wells tapping deeper fractured zones in hard rocks varies from 2-10 lps.

iv) *Coastal Areas*: Coastal areas have a thick cover of alluvial deposits of Pleistocene to Recent and form potential multi-aquifer systems covering states of Gujarat, Kerala, West Bengal, Tamil Nadu, Andhra Pradesh and Orissa. However, inherent quality problems and the risk of seawater ingress impose severe constrains in the development of these aquifers. In addition, ground water development in these areas is highly vulnerable to up-coning of saline water. The yield of the wells varies from 20-25 lps.

v) *Cenozoic Fault Basin and Low Rainfall Areas*: This region has been grouped separately owing to its peculiarity in terms of presence of three discrete fault basins, the Narmada, the Purna and Tapti valleys, all of which contain extensive valley fill deposits. The fill ranges in thickness from about 50 to 150 m. The aquifer systems in arid and semi-arid tracts of this region in parts of Rajasthan and Gujarat receive negligible recharge from the scanty rains and the ground water occurrence in these areas is restricted to deep aquifer systems tapping fossil water. For example, in parts of Purna valley the ground water is extensively saline and unfit for drinking and other purposes. The yield potential of the wells varies from 1-10 lps.

Ground Water Resources Estimation

Rainfall is the major source of ground water recharge in India, which is supplemented by other sources such as recharge from canals, irrigated fields and surface water bodies. A major part of the development of ground water resources takes place from the upper unconfined aquifers, which is also the active recharge zone and holds the dynamic ground water resource. The dynamic ground water resource in the active recharge zone in the country has been assessed by Central Ground Water Board in association with the concerned State Government authorities and the National Bank for Agricultural and Rural Development (NABARD). The assessment was carried out with Block/Mandal/Taluka/Watershed as the assessment unit and as per norms recommended by the Ground Water Estimation Committee (GEC)-1997. As per the latest estimates of 2004, the annual replenishable ground water resource in this zone has been estimated as 433 Billion Cubic Meters (BCM), out of which 399 BCM is considered to be available for development for various uses. The remainder of 34 BCM is set aside for natural discharge during non-monsoon period for maintaining flows in springs, rivers and streams. The state-wise ground water resources availability, utilization, stage of development and categorization is given in Table-1. The ground water resources availability and utilization in India is pictorially presented in Figure 2.

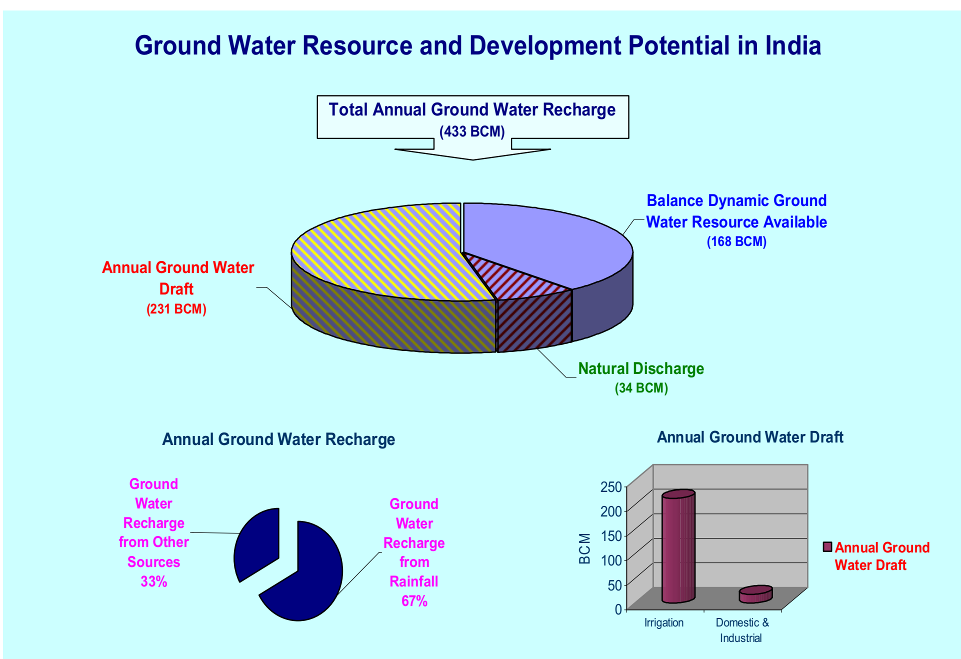

Fig.2: Ground water Resources Availability & Utilization in India

In addition to the resources available in the zone of water level fluctuation, extensive ground water resources have been proven to occur in the confined aquifers in the Ganga-Brahmaputra alluvial plains, coastal areas and deltaic tracts. These aquifers have their recharge zones in the upper reaches of the basins. The resources in these deep-seated aquifers are termed 'In-storage ground water resources'. In alluvial areas, these resources are normally renewable over long periods of time, except in cases like the 'Lathi' aquifers in Rajasthan, which comprise essentially non-renewable fossil water. Tentative estimates put the total quantum of in-storage ground water resources at about 10,800 BCM

Table.1. State-wise Ground Water Resources Availability, Utilization and Stage of Development in India (in BCM)

Sl. No.	States / Union Territories	Annual Replenishable Ground Water Resources	Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft	Stage of Ground Water Development (%)	Categorization of assessment Units (numbers)	
							Over-exploited	Critical
1	2	3	4	5	6	7	8	9
	States							
1	Andhra Pradesh	36.5	3.55	32.95	14.9	45	219	77
2	Arunachal Pradesh	2.56	0.26	2.3	0.0008	0.04	0	0
3	Assam	27.23	2.34	24.89	5.44	22	0	0
4	Bihar	29.19	1.77	27.42	10.77	39	0	0
5	Chhattisgarh	14.93	1.25	13.68	2.8	20	0	0
6	Delhi	0.3	0.02	0.28	0.48	170	7	0
7	Goa	0.28	0.02	0.27	0.07	27	0	0
8	Gujarat	15.81	0.79	15.02	11.49	76	31	12
9	Haryana	9.31	0.68	8.63	9.45	109	55	11
10	Himachal Pradesh	0.43	0.04	0.39	0.12	30	0	0
11	Jammu & Kashmir	2.7	0.27	2.43	0.33	14	0	0
12	Jharkhand	5.58	0.33	5.25	1.09	21	0	0
13	Karnataka	15.93	0.63	15.3	10.71	70	65	3
14	Kerala	6.84	0.61	6.23	2.92	47	5	15
15	Madhya Pradesh	37.19	1.86	35.33	17.12	48	24	5
16	Maharashtra	32.96	1.75	31.21	15.09	48	7	1
17	Manipur	0.38	0.04	0.34	0.002	0.65	0	0
18	Meghalaya	1.15	0.12	1.04	0.002	0.18	0	0
19	Mizoram	0.04	0.004	0.04	0.0004	0.9	0	0
20	Nagaland	0.36	0.04	0.32	0.009	3	0	0
21	Orissa	23.09	2.08	21.01	3.85	18	0	0
22	Punjab	23.78	2.33	21.44	31.16	145	103	5
23	Rajasthan	11.56	1.18	10.38	12.99	125	140	50
24	Sikkim	0.08	0	0.08	0.01	16	0	0
25	Tamil Nadu	23.07	2.31	20.76	17.65	85	142	33
26	Tripura	2.19	0.22	1.97	0.17	9	0	0
27	Uttar Pradesh	76.35	6.17	70.18	48.78	70	37	13
28	Uttarakhand	2.27	0.17	2.1	1.39	66	2	0

Sl. No.	States / Union Territories	Annual Replenishable Ground Water Resources	Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft	Stage of Ground Water Development (%)	Categorization of assessment Units (numbers)	
							Over-exploited	Critical
1	2	3	4	5	6	7	8	9
29	West Bengal	30.36	2.9	27.46	11.65	42	0	1
	Total States	**432.42**	**33.73**	**398.7**	**230.4**	**58**	**837**	**226**
	Union Territories							
1	Andaman & Nicobar	0.33	0.005	0.32	0.01	4	0	0
2	Chandigarh	0.023	0.002	0.02	0	0	0	0
3	Dadra & Nagar Haveli	0.063	0.003	0.06	0.009	14	0	0
4	Daman & Diu	0.009	0.0004	0.008	0.009	107	1	0
5	Lakshadweep	0.012	0.009	0.004	0.002	63	0	0
6	Pondicherry	0.16	0.016	0.144	0.151	105	1	0
	Total UTs	**0.597**	**0.036**	**0.556**	**0.181**	**33**	2	0
	Grand Total	**433.02**	**33.77**	**399.25**	**230.6**	**58**	**839**	**226**

Ground Water Development Status

Growth of Ground Water Abstraction Structures

Ground water extraction for various uses and evapotranspiration from shallow water table areas constitute the major components of ground water draft. In general, the irrigation sector remains the main consumer of ground water. Data available from the census of minor irrigation structures (Table.2) indicates a three-fold increase in the number of ground water abstraction structures from about 6 million during 1982-83 to about 18.5 million during 2001-02 (Fig.3).

Table.2 Growth of Ground Water Abstraction Structures in India (1982-2001)

Type of Structure	Number of Structures			
	1982-1983	**1986-1987**	**1993-1994**	**2000-2001**
Dug well	5384627	6707289	7354905	9617381
Shallow Tube well	459853	1945292	3944724	8355692
Deep Tube well	31429	98684	227070	530194

It is also seen that the growth has been more pronounced in shallow and deep tube wells (17 to 18 times) when compared to dug wells (about 2 times). This shift is probably the combined result of deepening ground water levels and advances in drilling and pumping technology. The ground water draft for the country as a whole has been estimated as 231 BCM, about 92 percent of which is utilized for irrigation and the remaining 8 percent for domestic uses. Hence, the stage of ground water development, computed as the ratio of annual ground water draft to net annual

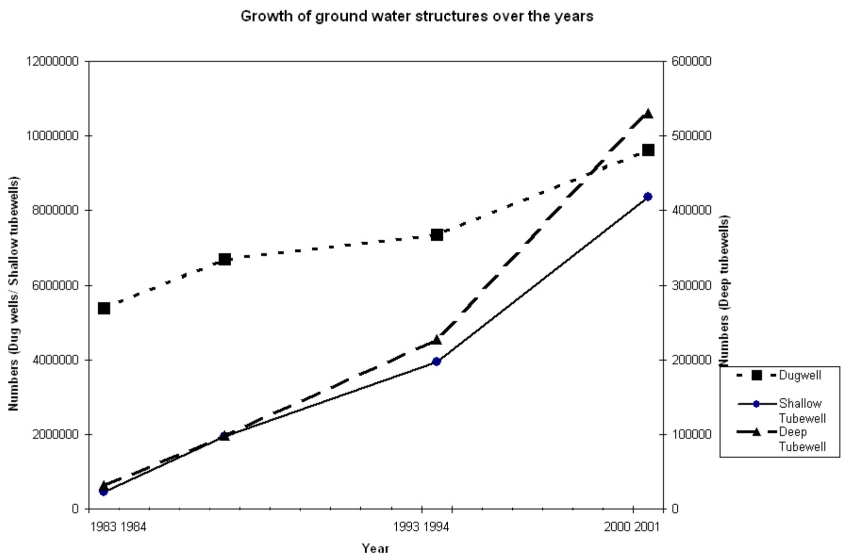

Fig.3 Growth of Ground Water Abstraction Structures in India
(Source: Minor Irrigation Census, 2001)

ground water availability, works out as about 58 percent for the country as a whole. However, the development of ground water in the country is highly uneven and shows considerable variations from place to place.

Categorization of Assessment Units

As part of the resource estimation as per GEC -1997 norms, the assessment units have been categorized based on the stage of ground water development and long term declining trend of ground water levels. As per the assessment, out of the total of 5723 assessment units in the country, ground water development was found to exceed more than 100 % of the natural replenishment in 839 units, which have been categorized as 'Over-exploited'. Ground water development was found to be to the extent of 90 to 100 percent of the utilizable resources in 226 assessment units, which have been categorized as 'Critical'. The categorization of assessment units for the country is shown in Fig.4.

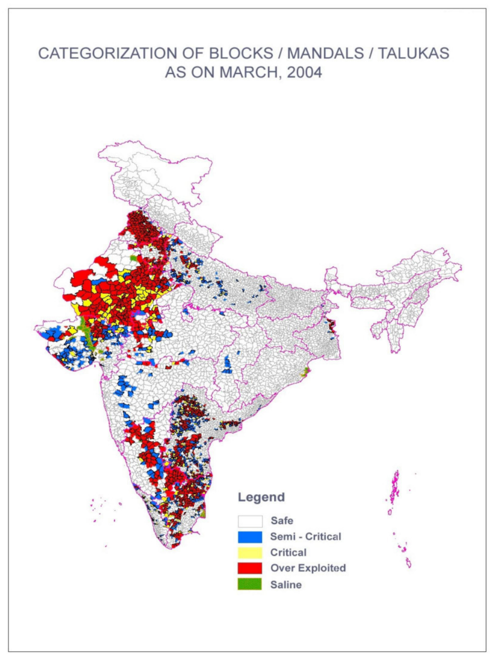

Fig-4 Categorization of Assessment Units Based on the Stage of Ground Water Development in India (As on March 2004)

The variability in the distribution of ground water resource and its utilization is clearly seen in the data provided in Table -1. It is seen that the stage of ground water development ranges from 0.04 percent in Arunachal Pradesh to 170 percent in Delhi. The states of Andhra Pradesh, Tamil Nadu, Rajasthan and Punjab account for more than 70 percent of the total number of overexploited assessment units in the country as a whole.

Rainfall Variations

The rainfall pattern of the country is evident form the Isohyetal map (Fig-5) of the country showing the annual normal rainfall.

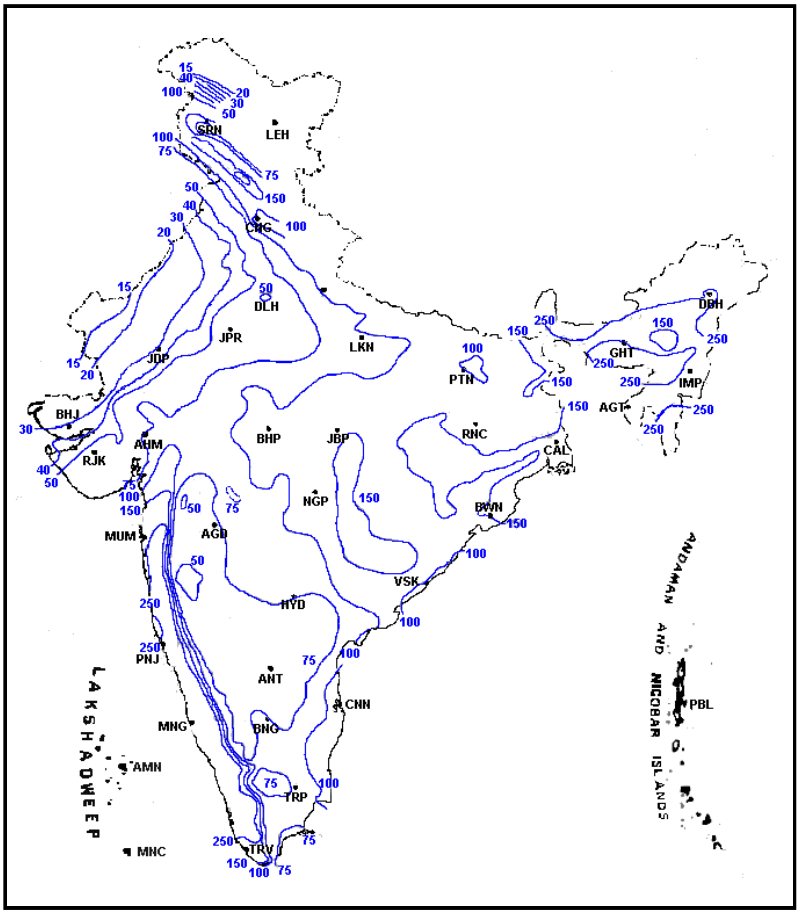

Fig- 5 Map showing the Annual Normal Rainfall (in cm.)

In India, rainfall is unevenly distributed spatially and temporally. The average rainfall of the country is around 117 cm. From the perusal of isoheytal map it can be observed that the rainfall is below 75 cm in the north western part of the country covering major part of the states of Rajasthan, Gujarat, Haryana, and in the southern part, in the states of Karnataka and Tamil Nadu. A review of annual ground water availability, contribution from monsoon rainfall recharge and annual ground water draft in different states falling under overexploited category and the rainfall distribution in space brings a paradoxical situation in the sense that, withdrawal of ground water is not solely responsible for declining trends, the scantly and low rainfall resulting in meager monsoon recharge is equally important. Majority of the ground water stress areas categorized as overexploited and critical units also lies in these states.

The variations in depth to ground water level in the country during pre-monsoon and post monsoon period is shown in Fig-6a & 6b.

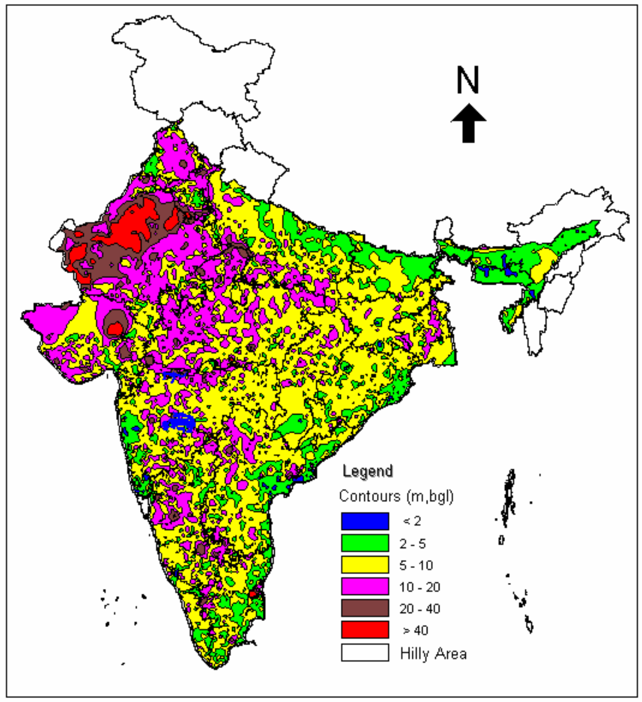

Fig-6a Map Showing Depth to Water Level (Pre-Monsoon, 2006)

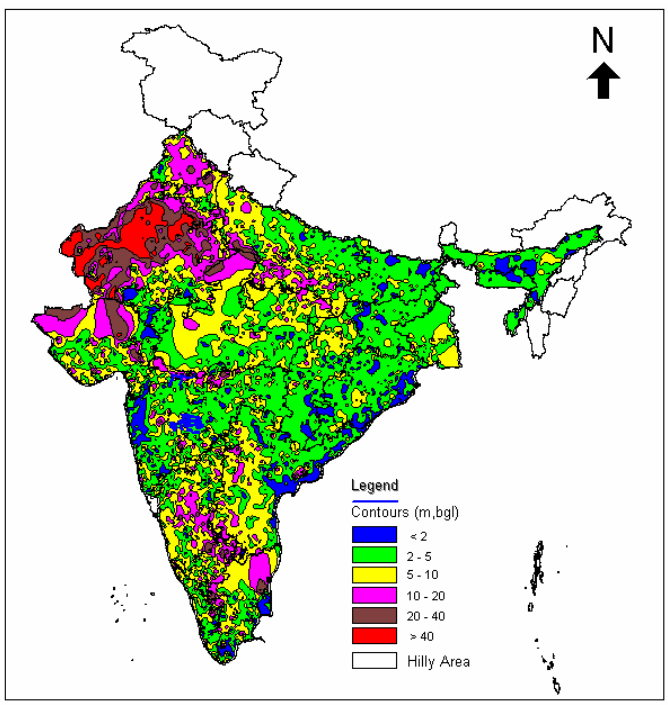

Fig-6b Map Showing Depth to Water Level (Post-Monsoon, 2006)

It has been observed that deepest water levels of 40 m and above are common in the western part of the country which is also the zone of low rainfall resulting in meager natural ground water recharge.
Quality of Ground water

As regards quality, the ground water in the major part of the country is potable and suitable for irrigation and industrial uses, except in few areas where they have been rendered non-potable due to the presence of geogenic contaminants such as Fluoride, Iron, Arsenic etc. in excess of limits prescribed for human consumption. These include Inland salinity problems in the arid and semi-arid regions of Rajasthan, Haryana, Punjab and Gujarat, arsenic hazards in Gangetic alluvial belt, iron contamination in Brahmaputra and Kosi river basins, fluoride problems in hard rock areas of Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Karnataka etc. Excessive withdrawal of ground water may also lead to salinity ingress and consequent ground water contamination as experienced in coastal areas of Mangrol-Chorwad tract and coastal Saurashtra of Gujarat and in Minjur area south of Chennai in Tamil Nadu. Ground water pollution due to domestic and industrial effluents and excessive application of fertilizers and pesticides are also observed, mostly as localized phenomenon.

Various issues discussed above bring the complexities involved in managing the ground water resources of the country. There is an urgent need to prepare a vision document focusing the efficient measures for ground water management to combat the emerging problems of water scarcity. An attempt has been made in this direction.

Management of Ground Water Resources

Management of ground water resources in a country as vast and diverse as India is an extremely complex proposition as it deals with the interactions between the human society and the physical environment. The highly uneven distribution of ground water availability and its utilization indicates that no single management strategy can be adopted for the country as a whole. On the other hand, each situation demands a solution which takes into account the geomorphic set-up, climatic, hydrologic and hydrogeologic settings, ground water availability, water utilization pattern for various sectors and the socio-economic set-up of the region.

Any strategy for scientific management of ground water resources involves a combination of A) Supply side measures aimed at increasing extraction of ground water depending on its availability and B) Demand side measures aimed at controlling, protecting and conserving available resources. Various options falling under these categories are described in detail in the following sections.

Supply Side Measures

As already mentioned, these measures are aimed at increasing the extraction of ground water depending on its availability, taking the environmental, social and economic factors into consideration. These are also known as ‘structural measures’, which involves scientific development and augmentation of ground water resource. Development of available ground water resources through suitable means and augmentation through rainwater harvesting and artificial recharge fall under this category. For an effective supply-side management, it is imperative to have full knowledge of the hydrologic and hydrogeologic controls that govern the yields of aquifers and behavior of ground water levels under abstraction stress. Interaction of surface and ground water and changes in flow and recharge rates are also important considerations in this regard.

Scientific Development of Ground Water Resources

Ground Water Development in Alluvial Plains

Scientific studies have proven that ample reserve of ground water is available in the areas underlain by Indo-Gangetic and Brahmaputra alluvial plains in the northern and northeastern parts of the country. Coincidently, the ground water development in these areas are sub-optimal, in spite of the availability of resources, and offers considerable scope for ground water development in future. In addition to the sufficient availability of dynamic ground water resources in the phreatic zone, there is a vast in-storage ground water resource in the deeper zones i.e. below the zone of ground water fluctuation. The estimates of in-storage ground water resources on pro-rata basis down to a depth of 400 m works out to be 10812 BCM , out of which nearly 10633 BCM is available in the areas occupied by alluvial and unconsolidated formations. Surprisingly the three major States occupying the Alluvial plains i.e. Uttar Pradesh, Bihar and West Bengal , has a share of the in storage ground water resources to the tune of 7652 BCM which is more than 70% of the total.

Fragmented land holdings, poor socio-economic status, poor infrastructure facilities, and lack of knowledge of modern technologies are some of the reasons for the under-utilization of ground water resources in these areas, in spite of the growing need for boosting agricultural production. In this context, there is an urgent need to explore various options for optimal utilization of these resources. One of the management measures could be to adopt the concept of ***Virtual water***. Virtual water is defined as water embedded in commodities. It is said that the largest exported commodity in the world is “Water”, which is in terms of virtual water contained in the food grains. As a thumb rule, a grain of crop transpires about 1 cubic meter of water in order to produce 1 kilogram of grain. Thus, exporting or importing 1 kilogram of grain is approximately equivalent to exporting 1 cubic meter of water. The best example of virtual water in Indian context can be thought in terms of producing fodder in the water surplus areas of Indo-Gangetic plains and transported to the water stressed areas of Gujarat, Rajasthan, Punjab etc. This way, water used for fodder production in these states can be reduced and water saved can be fruitfully utilized for other priority sectors.

At the same time, there is an urgent need for Government financed schemes for planned scientific ground water development in these areas. Such schemes should be implemented, considering the socio-economic conditions of the beneficiaries and should be managed through community participation functioning under the broader spirit of cooperative movement.

Ground Water Development in Coastal Areas

Many parts of the coastal areas of India have thick deposits of sediments ranging in age from Pleistocene to recent, which have given rise to multi-aquifer systems of good potential. There is considerable scope for development of ground water from such aquifer systems. However, development of ground water from such aquifers needs to be done with caution and care should be taken to ensure that over-exploitation of resources does not lead to saline water intrusion. Large diameter dug wells, filter point wells and shallow tube wells are ground water abstraction structures best suited for such aquifers. Radial wells and infiltration galleries can also be constructed in areas where the requirement of water is large. As the multi-aquifer systems in coastal areas are likely to have all possible dispositions of fresh and saline waters, it is necessary to take up detailed studies to establish the saline–fresh water interface and establish the dynamics of discharge of ground water to sea. This will ensure the implementation of ground water development plans. Further, sanctuary wells need to be constructed in hydrogeologically suitable areas to meet the water requirement during unforeseen situations like Cyclonic disasters, Tsunamis etc.

Ground Water Development in Hard Rock Area

The hard rock areas are characterized by considerable heterogeneity and anisotropy and the aquifers are normally discontinuous and of limited ground water potential. In spite of their limited potential, these aquifers play an important role in meeting the drinking, agricultural and industrial needs in the peninsular shield areas of the country. In spite of the relatively high stage of ground water utilization in the hard rock terrain, there is further scope for development in many States including Kerala, Tamil Nadu, Karnataka and Maharashtra. Any scheme for further ground water development in such areas should be preceded by detailed studies for identification of area suitable for ground water development. Modern technologies in the fields of remote sensing and Geographical Information Systems (GIS), coupled with conventional hydrological and hydrogeological surveys can be used for demarcating areas suitable for further ground water development in such terrain. Shallow and deep buried pediments, valley fills, bazada zones and flood plains of streams offer ideal locales for construction dug wells and dug cum bore wells, whereas intersection of lineaments are ideal for construction of bore wells. However, there is a need to restrict the development from such aquifers within their recharging capabilities to ensure their long-term sustainability.

Ground Water Development in Water-logged Areas

Water-logging and soil salinity problems, resulting from gradual rise of ground water levels, are observed in many canal command areas due to the implementation of surface water irrigation schemes without due regard to environmental considerations. As per the assessment made by the Working Group on Problem Identification with Suggested Remedial Measures (1991), about 2.46 million hectare of land under surface water irrigation projects in the country is either water-logged or under threat of it. Such areas offer good scope for further ground water development as the shallow water table in such areas can be lowered down to six meters or more without any undesirable environmental consequences. The problems related to inferior quality of water in such areas can be solved by mixing them with the canal waters available. Judicious development through integrated use of surface and ground water resources can greatly reduce the menace of water-logging and salinity in canal irrigated areas. Such efforts will also be in line with the directives of National Water Policy which states that surface and ground water should be viewed as an integrated resource and should be developed conjunctively in coordinated manner and their use should be envisaged right from the project planning stage.

Ground Water Development from Deep Aquifers

The stage of ground water development is rather high in the States of Haryana, Punjab and Rajasthan and a large number of over-exploited and critical assessment units fall in these states. Studies by CGWB in the Indo-Gangetic basin in Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal have revealed the existence of deep-seated aquifers storing voluminous quantity of ground water. Fresh ground water has been reported down to a depth of about 700 m in Uttar Pradesh. Exploratory studies carried out by ONGC in the Gangetic alluvium indicated existence of fresh ground water at more than 1000 m depth. Similarly, free flow of ground water due to artesian conditions exists in some areas like Tarai and sub-Tarai belt of Uttar Pradesh and Bihar. As no energy is required for extraction of ground water from such aquifers, development of ground water from these auto-flow zones is both economically viable and eco-friendly.

Development of Flood Plain Aquifers

Flood plains of rivers are normally good repositories of ground water and offers excellent scope for development of ground water. Ground water levels in these tracts are mostly shallow, leaving little room for accommodating the monsoon recharge, a major portion of which flows down to the river as surface (flood) and sub-surface runoff. A planned management of water resource in these tracts can capture the surplus monsoon runoff, which otherwise goes waste. The strategy involves controlled withdrawal of ground water from the flood plains during non-monsoon season to create additional space in the unsaturated zone for subsequent recharge/infiltration during rainy season.

There are two distinct conditions as regards induced recharge from the river/stream to ground water aquifer. The first condition involves setting up a hydraulic connection between the aquifer and the river as recharge boundary due to heavy exploitation of ground water and expansion of cone of depression. This condition is common in case of perennial rivers and leads to changes in river flow conditions in the down stream. The hydraulic connection between the river and the aquifer ceases as soon as pumping is stopped.

The second scenario is more common in case of rivers having intermittent flows; the loose sediments in the flood plains are more or less saturated resulting into shallower ground water levels. The heavy withdrawal of such flood plain aquifers during the non-monsoon creates ample space in the ground water reservoir which gets recharged by the river during the flood season. In absence of such created space the river water would overflow. This condition is more prevalent in Indian scenario and provides opportunity for augmentation of ground water reservoir through induced recharge.

A study in this regard was taken up in northern part of Yamuna flood plain area in Delhi (Fig.7) wherein Central Ground Water Board constructed 95 tube wells in Palla Sector in the depth range of 38-50 m for Delhi Jal Board, the domestic water supply agency of the State. On the basis of scientific studies, it was found out that nearly 30 MGD of water can be safely drawn from these tube wells during monsoon and non-monsoon seasons to meet drinking water requirements of National Capital Territory, Delhi. In this process, a part of flood water (rejected recharge) is utilized to augment sub-surface storage during monsoon.

The experience of Yamuna flood plains in Delhi has shown the scope of enhancing ground water recharge by pumping to lower the water table ahead of the rainy season and thus creating more space for the flood water to percolate. The concept can be implemented in similar situations in different parts of the country after carrying out detailed study on the hydrodynamics of the flood plain zones involving stream-aquifer interaction.

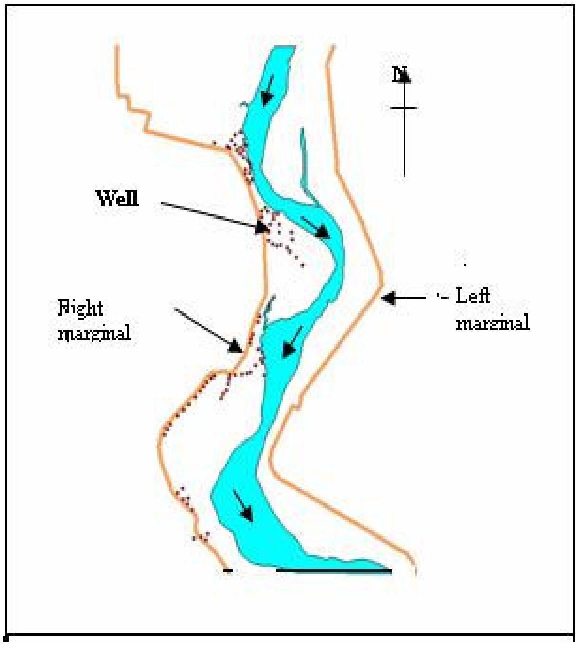

Fig. 7: Ground Water Development in Yamuna Flood Plain, Palla, Delhi

Augmentation of Ground Water Resources

Rainwater Harvesting and Artificial Recharge to Ground Water

Rainwater harvesting and artificial recharge have now been accepted worldwide as cost-effective methods for augmenting ground water resources and for arresting/reversing the declining trends of ground water levels. Artificial recharge techniques are highly site-specific. Suitability of area in terms of availability of sub-surface storage space and availability of surplus monsoon run-off are important considerations for successful implementation of artificial recharge schemes.

Rainwater harvesting and artificial recharge schemes implemented by various organizations in the country including Central Ground Water Board have shown encouraging results in terms of augmentation of ground water recharge, check in rate of decline of ground water levels and reduction of surplus run off. Increased sustainability of existing abstraction structures, increase in irrigation potential, revival of springs, soil conservation through increase in soil moisture and improvement in ground water quality are among other benefits of the schemes. In the coastal tracts, tidal regulators, constructed to impound the fresh water upstream and enhance the natural recharge are effective in controlling salinity ingress. Pilot schemes implemented by CGWB during VIII and IX plan periods have indicated the efficacy of Percolation tanks, check dams, recharge shafts and sub-surface barriers in augmenting ground water resources in the hard rock areas of Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra and Tamil Nadu. Recharge trench, recharge shaft and recharge tube wells are found to be the most suitable structures for recharge augmentation in alluvial areas. Schemes implemented in Haryana, Punjab, Delhi and Chandigarh have shown rise in water level in the range 0.25 to 0.70 m.

Experience gained from pilot artificial recharge schemes implemented by Central Ground Water Board in different hydrogeological settings in the country has indicated that optimal benefits can be achieved when various recharge structures are constructed at suitable locations in complete hydrological units such as watersheds, sub-basins etc. The percolation tank with recharge shaft suited to rural areas is constructed at Randan Khedi, District, Dewas, M.P is shown in Fig 8, similarly, a typical roof top rain water harvesting and ground water recharge through dug well suiting to urban areas constructed at Musa Kheri, Indore town is shown in Fig.9.

Central Ground Water Board has also carried out studies for demarcating areas of long-term decline of ground water levels and for exploring the possibility of augmenting the ground water resources in these aquifers using available surplus monsoon runoff. An area of about 4.5 lakh sq km has been identified in the country where such augmentation measures are considered necessary. It has also been estimated that about 36 BCM of surplus monsoon runoff can be recharged into these aquifers annually (CGWB, 2002). Modification of natural movement of surface water into the aquifers through various structures like check dams, percolation ponds, recharge pits, shafts or wells are considered suitable in rural areas. On the other hand, roof-top rainwater harvesting, either for storage and direct use or for recharge into the aquifers is suited for urban habitations with its characteristic space constraints.

Regular and proper maintenance of structures is a necessary prerequisite for the success of any artificial recharge scheme. This can be ensured only through active participation of stake holders. At present, rainwater harvesting and artificial recharge schemes are mostly implemented through government and non-governmental initiatives. There is a need to shift the initiative from institutional endeavor and make it into a mass movement. Community based programmes on rain water harvesting and artificial recharge would inculcate a sense of responsibility among the stake holders, thereby enhancing the efficiency level of maintenance of the schemes.

Fig. 8 - Percolation Tank with Recharge Shaft at Randan Khedi, District, Dewas, M.P.

Fig 9 - Roof Top Rain Water Harvesting and Ground Water Recharge Through Dug Well at Musa Kheri, Indore Town, M.P.

Demand Side Measures

Apart from scientific development of available resources, proper ground water resources management requires to focus attention on the judicious utilization of the resources for ensuring their long-term sustainability. Ownership of ground water, need-based allocation and pricing of resources, involvement of stake holders in various aspects of planning, execution and monitoring of projects and effective implementation of regulatory measures wherever necessary are the important considerations with regard to demand side ground water management.

Ownership of Ground Water

Ownership is an important issue to be resolved before implementation of any strategy for managing ground water resources. In spite of the importance being given to ground water resources in our country, the legal position regarding ownership of ground water is still not very clear. The absolute ownership concept, embodied in the Indian Easement Act 1882, has paved way for unlimited extraction of ground water by the land owners. One of the consequences of this law is the ownership of all ground water by the land owners, while the landless laborers and poor tribals are left out. The over-exploitation of ground water resources by rich farmers adversely affects the small and marginal farmers, whose wells may go dry in course of time. However, a close reading of the relevant portion of clause 7 of the Act gives a new insight. The act says;

"The right of every owner of land *to collect and dispose within his own limits of all water under the land which does not pass in a defined channel* and all water on its surface which does not pass in a defined channel."

It has been proved that ground water is a dynamic resource and flows in a definite direction. Pumping of ground water from any abstraction structure affects the flow pattern. Hence, the right of a land owner to collect or dispose water within his land can be argued to be limited to the quantum which will not adversely affect the flow pattern. This matter should be taken up at appropriate government level to clarify the legal position of ground water ownership.

Pricing and Sectoral Allocation of Ground Water

It is increasingly being recognized that while maintaining its social characteristics, water is to be considered an economic good. Irrigation and water supply projects have traditionally been viewed as instruments of development, social benefits and as net addition to agricultural output and the national economy. In the domestic sector too, water is treated as a basic human need, to be made available to everybody irrespective of economic status. Thus, pricing of water in actual terms has not been implemented so far. However, undue advantage of this social stance on water pricing is being taken by the affluent class of the society. Affluent farmers, water intensive industries, water based amusement centres, posh urban residential colonies are enjoying the benefits of highly subsidized price of water even though they can afford to pay the actual cost. Since water is available without any financial liabilities worth bothering, these water guzzling instruments are indiscriminately extracting ground water without paying any heed to environmental or social considerations. Hence, there is a need to allocate water at a cost commensurate with demand among various users as the present pricing structure does not provide necessary incentives for its efficient use. Pricing of ground water can play a very important role in increasing water use efficiency.

The rate of ground water withdrawal is also intimately related to the power tariff. A major part of electricity delivered to the agriculture sector is used to pump ground water for irrigation. Presently, power is supplied to rural areas at highly subsidized rates or at flat rates, rather than based on actual power consumption. The highly subsidized rate, combined with inefficient and unreliable power supplies encourages indiscriminate withdrawal of ground water and sale of water in informal water markets. Provision for unmetered power to the agricultural sector creates an accountability gap and generates opportunities for large unaccounted losses. Restoration of financial viability of the power sector through appropriate pricing as a first step will be essential for ensuring the long-term sustainability of ground water resources. The revision of power tariffs should of course be combined with improved quality and reliability of power supply. The Government of Gujarat, under its *Jyotigram Yojana,* has evolved an innovative approach for rural power supply. Separate feeders were provided for domestic power supply and irrigation use. Villages get 24 hour three- phase power supply for domestic uses subject to metered tariff, whereas tube well owners get eight hours/day of power, but of full voltage and on a pre-announced schedule (Shah and Verma, 2007). The experience in Gujarat shows that redesigning of power supply mechanism can be effective in controlling the electricity consumption and thereby reducing ground water withdrawal.

Ground water is a dynamic resource occurring in regionally inter-connected systems. Any change in the pattern of development in one part of the system tends to affect the availability, quality and economics of supplies elsewhere in the system. The absence of a clear and well-defined ground water allocation policy for various sectors has the potential to foster unhealthy competition among users of this common pool resource. This may result in indiscriminate withdrawal of ground water in a bid to get maximum benefit before it is exhausted, and may widen the demand supply gap considerably. A well thought of water allocation policy is urgently required to address this problem and to ensure equitable distribution of available resources with built-in safeguards for its sustainability wherever necessary.

Regulation of Ground Water Development

Regulation of over-exploitation of ground water through legal means can be effective under extreme situations if implemented with caution. Ground water regulatory measures in India are implemented both at Central and State level. The central Ground Water Authority, constituted under Environment (Protection) Act of 1986 is playing a key role in regulation and control of ground water development in the country. Central Ground Water Authority initially notifies over-exploited areas in a phased manner for registration of ground water abstraction structures. 65 areas in various parts of the country have been notified for registration of ground water abstraction structures. Based on data thus generated, vulnerable areas are notified for the purpose of ground water regulation. So far, CGWA has notified 43 areas for regulation of ground water use. In these areas, construction of new ground water abstraction structures is regulated.

As water is a State subject, the management of ground water resources is a prerogative of the concerned State Government. In an effort to control and regulate the development of ground water, the Ministry of Water resources has prepared and circulated a Model Bill to all States and Union Territories in 1970 which was re-circulated in 1992, 1996 and 2005 for adoption. The main thrust of the bill is to ensure that all the States and Union Territories form their own State Ground Water Authorities for proper control and regulation of ground water resources. Some of the States like Andhra Pradesh, Bihar, Goa, Tamil Nadu, Himachal Pradesh, Kerala, and West Bengal and the Union Territories of Puducherry (Pondicherry), Chandigarh and Lakshadweep have already enacted ground water legislation.

As water is a basic need and thereby an important social issue, the regulatory mechanism needs to be transparent and people-friendly. Continuous monitoring of ground water regime is required in notified areas. Micro-level studies needs to be taken up in such areas on a regular basis to assess the impacts of the regulatory measures on the ground water regime. Real-time dissemination of information on the ground water situation in the affected areas is to be provided to the stakeholders. Involving local people in the administrative process as social volunteers may also help.

International experiences in ground water regulation and management are varied. United States ground water management practices are more in the form of financial incentives. In Spain and Mexico, water laws are formulated making ground water a national property. However, implementation of various clauses of ground water legislation could not be effectively achieved on a large scale in these countries (Planning Commission, 2007). National and international experiences indicate that enforcement of legislative measures for ground water regulation and management would be meaningful only when stakeholders are motivated through local self governing bodies and directly involved in the decision-making and enforcement process.

Water Saving Measures

Studies have shown that substantial quantity of water could be saved by the introduction of micro irrigation techniques in agriculture. Micro irrigation sprinklers and drip systems can be adopted for meeting the water requirement of crops on any irrigable soils except in very windy and hot climates. These water conservation techniques would provide uniform wetting and efficient water use. Although much of this can be achieved through private sector initiatives, it is important to ensure the availability of credit for purchasing equipments. In addition, mechanisms for encouraging adoption of these techniques by lower-income groups also need to be put in place.

Changes in cropping pattern aimed at higher return of investment may lead to increased exploitation of ground water, as the experiences in Punjab and Haryana have shown. Suitable scientific innovations may be necessary to solve this issue. Less water intensive crops having higher market value, scientific on-farm management, sharing of water and rotational operation of tube wells to minimize well interference and similar alternatives can provide viable solutions for balancing agro-economics with environmental equilibrium.

Broadening the limits of the quality of water used in agriculture can help manage the available water better in areas where scarcity of water is due to salinity of the available ground water resources. Cultivation of salt tolerant crops in arid/semi-arid lands, dual water supply system in urban settlements - fresh treated water for drinking water supply and brackish ground water for other domestic uses are some such examples. Recycling of water after proper treatment for secondary and tertiary uses is another alternative that could be popularized to meet requirements of water in face of the scarcity of resource in the cities.

Stakeholder Participation and Awareness

Unlike major and medium irrigation projects which are mostly State-run, most of the ground water development schemes result from private initiatives. The onus of management of this resource, therefore, lies with the people. Implementation of any large scale ground water development scheme is not likely to succeed, unless peoples' participation is ensured in planning, execution, and operation and maintenance of the scheme. However, due to lack of awareness, there is considerable lack of initiative at present from the stakeholders in addressing the management needs of the ground water sector. In order to involve the water users and the private sector in water management initiatives, it is necessary that comprehensive information pertaining to the ground water regime, both qualitative and quantitative, be made available to the stakeholders on a regular basis. Such an initiative is likely to motivate the users to take an active interest and involve themselves in the process of sustainable management of ground water resources. A shared understanding of the problems with the stakeholders can also generate the much needed financial resources and expertise to prove that ground water resources can be profitably managed. There is an urgent need to make a concerted effort on sharing of knowledge and information on ground water science with the common people through various platforms involving educational institutions, non-Governmental organizations, social activist groups, local self governing bodies etc. so that an integrated plan for management of our limited ground water resources can be implemented to ensure their long-term sustainability.

Conclusions

The increasing dependence on ground water as the major source of water supplies for agricultural, domestic and industrial sectors in India, coupled with the indiscriminate and unscientific exploitation of the limited available resources has necessitated a reorientation of the strategies of ground water management to ensure its long-term sustainability. The highly diversified hydrogeologic settings and variations in the availability of ground water resources as total and in terms of natural rainfall recharge from one part of the country to another call for a holistic approach for development of suitable management strategies. The emphasis on management does not imply that ground water resources in India are fully developed. There is a vast area in the Indo Gangetic alluvial tract where the ground water development is at low key and there is sufficient scope for future development. Similarly, urgent action is required to augment the ground water in the stress areas. However, focus on development activities must now be balanced by management mechanisms to achieve a sustainable utilization of ground water resources. Effective management of available ground water resources requires an integrated approach, combining both supply side and demand side measures. There is need for coordinated efforts from various Central and State Government agencies, non-Governmental and social service organizations, academic institutions and the stakeholders for planning and implementing management strategies suitable for the prevailing situations to ensure the long-term sustainability of ground water resources in the country.

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