Groundwater Management – Emerging Challenges

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Abstract: Ground water is poorly understood but most sought after resource for meeting the ever-growing demands of different user groups. The stress on groundwater systems is reflected in steep decline of water levels and sharp deterioration in quality of water. The major challenge is the proper understanding of the dynamics of groundwater flow under different hydrogeological conditions in space and time. A scientific development and management of ground water is the need of the time to avert any future crisis. In addition to this, the management strategies cover a wide range of subjects such as ownership of ground water, allocation and pricing of resources, effective regulation and role of stakeholders. An attempt has been made in this paper to look into all these important aspects to help in evolving a scientific policy for groundwater management, which can assure long-term sustainability of this fast depleting resource.

INTRODUCTION

Groundwater resources play a very important role in meeting the ever-increasing demands of agriculture, industry and domestic sectors. At present, more than 85% of domestic water supply in rural areas, about 50% of water requirements for urban areas and industries and more than 55% of irrigation water requirements are being met from ground water. Inspite of the importance of ground water in maintenance of India's economy it does not find its due share in planning processes for scientific development and management. Groundwater development is mainly done by private enterprises, witnessed in a phenomenal growth of groundwater abstraction structures during the last five decades. The unscientific and inefficient use of this vital resource is contributing to its increasing scarcity, reflected in steep decline of water levels and under certain situations in sharp deterioration in quality of water. This leads to misgiving in certain sections that groundwater availability scenario in the country has reached a critical stage and there is no scope for future development of ground water. The apparent crisis is more of management than of actual availability. Groundwater management is the key for the sustainability of this vital resource. Unfortunately, due to its nature of occurrence as a hidden resource, controlled by hydrogeological features, not much scientific stress is given to understand the dynamics of its flow in space and time. Demand driven exploitation without required regulatory measures and understanding of area specific problems, leads to crisis not only for the present but also may result in damage to groundwater system with adverse effect on future water supplies. The paper attempts to identify the urgent steps required for groundwater management, which may help in developing a scientific strategy to utilize this vital resource.

SCENARIO OF GROUNDWATER RESOURCES

The hydrogeological set up in the country varies widely. The lofty mountain chains in the north with high runoff, offers little scope for groundwater storage. However, they play an important role in recharging the vast Indo-Ganga-Brahmaputra plains flanked southwards. Multi-aquifer systems, explored down to 600 m, promises extensive and productive groundwater reservoirs. The peninsular shield in the south comprises discontinuous aquifers of limited potential in weathered and fissured consolidated sedimentaries, basalts and crystalline rocks. The coastal areas have a thick cover of Pleistocene to Recent alluvium with potential aquifers but associated with risk of sea water intrusions. The arid and semi-arid regions of Rajasthan and Gujarat with scanty rainfall and practically no recharge have restricted occurrence of deep aquifers tapping fossil water.

Rainfall is the main source of recharge to groundwater storage. Most of the groundwater development takes place from the dynamic zone of water level fluctuation in the unconfined aquifers where active recharge takes place. In this active recharge zone the annual replenishable groundwater resource for the country has been estimated as 433 Billion Cubic Metres (BCM). Out of this, 399 BCM is available for utilization, leaving aside 34 BCM for natural discharge. The total groundwater draft is 231 BCM of which 92% is for irrigation (213 BCM) and 8% is for domestic and industrial use (18 BCM). The overall stage of groundwater development is 58%. However, there is a large variation in development of groundwater in the country. Out of 5723 assessment units (blocks/mandals/talukas/watersheds), 839 are categorized as "Over-Exploited" where the stage of development exceeds annual replenishment and 226 blocks/watersheds are critical where groundwater development has reached a high level of development. The Statewise groundwater resources of the country are given in Annexure I and details of categorization of assessment units in Annexure II.

The scenario of the groundwater availability in the active recharge zone may give an alarming impression of scarcity of this resource. However, a huge potential of groundwater exists in the deeper confined aquifers found in the areas covered by alluvium in Ganga-Brahmaputra plains, coastal and deltaic tracts with recharge zone in upper reaches of the basins. These deeper aquifers are categorized under "passive recharge zones" with a huge quantity of groundwater recharged over a number of years. The groundwater resources of the deeper aquifers beyond the zone of dynamic fluctuation are termed "instorage groundwater resources". In the alluvial areas, these resources are renewable and get replenished over long period from recharge areas flanking the mountains. However, in some cases like the "Lathi aquifers" in Rajasthan the instorage resources comprise fossil water, which is of non-renewable nature. The tentative estimate of instorage fresh groundwater in the country is about 10,800 BCM (Annexure III).

GROUNDWATER MANAGEMENT STRATEGIES

Groundwater management deals with a complex interaction between human society and physical environment and presents an extremely difficult problem of policy design. Aquifers are exploited by human decisions and over-exploitation cannot be always defined in technical terms, but as a failure to design and implement adequate institutional arrangements to manage people who exploit the groundwater resources. 'Common pool' resources such as groundwater have been typically utilized in an 'open access' framework, within which, resource ownership is according to a rule of capture. When no one owns the resources, users have no incentive to conserve for the future, and self interest of individual users leads them to overexploitation.

The various management options available for ameliorating or solving problems related to groundwater quantity and quality can be broadly grouped under two major categories. The first category relates to supply side management and are referred as "structural measures" which involve scientific development and augmentation of groundwater resources. For an effective supply side management, it is essential to have full knowledge of hydrogeological controls which govern the yield and behaviour of groundwater levels under abstraction stress, the interaction of surface and groundwater in respect of river base flow and changes in flow and recharge rates due to their exploitation. The effects of groundwater development can be short term and reversible or long term and quasi-reversible which require a strong monitoring mechanism for scientific management. The other category encompasses Demand side management which is user targetted and are referred as "Non-structural Measures". In demand side management the socio-economic dimension plays an important role involving managing the users of water and land. Actions are required for proper resource allocation and prevention of the likely adverse effects of uncontrolled development of groundwater resources. Mere regulatory interventions like water rights and permits and economic tools of water pricing etc. cannot be successful unless the different user groups are fully involved to get their cooperation and participation. For effective management of groundwater resources there is a need to create awareness amongst the different water user groups and workout area specific plans for sustainable development. In a nut shell the first category of management options targets policies for 'managing the water' and the second category calls for 'coordinating the people'.

Structural Measures

Scientific Development of Ground Water

The major challenge for effective management of ground water is the scientific development of available resources. The lack of proper understanding of the local groundwater regime behaviour and demand driven development without addressing to management needs aggravates the situation. The need for scientific planning in development of ground water under different hydrogeological situations in the country is discussed below to provide the necessary insight for effective management of this vital and scarce resource.

Development of ground water in areas with low stage groundwater development: A large part of the country is covered with areas where the level of groundwater development is below 40%. Special attention is drawn to the eastern and north-eastern parts of the country, mainly in the States of Assam, Bihar, Orissa, UP and West Bengal, where small and marginal farmers are not able to afford the cost of sinking and energisation of wells due to their poor socio-economic status. Water marketing is prevalent in these areas, where effluent farmers having substantial land holdings, monopolise on groundwater extraction for selling to poor farmers. There is a great scope of groundwater development in these areas, which often faces floods during rainy seasons. The concept of virtual water is also very much relevant to such areas of low stage of groundwater development. In areas like Gujarat, where in addition to the requirement of water for dairy development, fodder for the cattles is also grown which leads to over-exploitation of ground water. If the fodder requirement is met from agriculture production in the eastern States a large quantity of water can be saved in the form of virtual water, hidden in the grains, which can be transported to water scarcity areas.

Development of deep aquifers: Stage of groundwater development is very high in the States of Haryana, Punjab, and Rajasthan and majority of the dark and over-exploited blocks fall in these States. However, there is ample scope of groundwater development from deeper aquifers in Punjab, Haryana and UP. The studies by CGWB in alluvial parts of Haryana and UP have revealed the existence of a huge reserve of ground water in the deeper aquifers, which has not been fully utilized. The thickness of the alluvium in the area exceeds 500 m and only a small fraction of this is under active circulation due to prevailing shallow groundwater development (Fig. 1). The under utilization of the ground water from deeper aquifers has resulted in near stagnant conditions at depth and provided the necessary time factor for the deterioration in quality of ground water. It was observed that calcium bicarbonate type

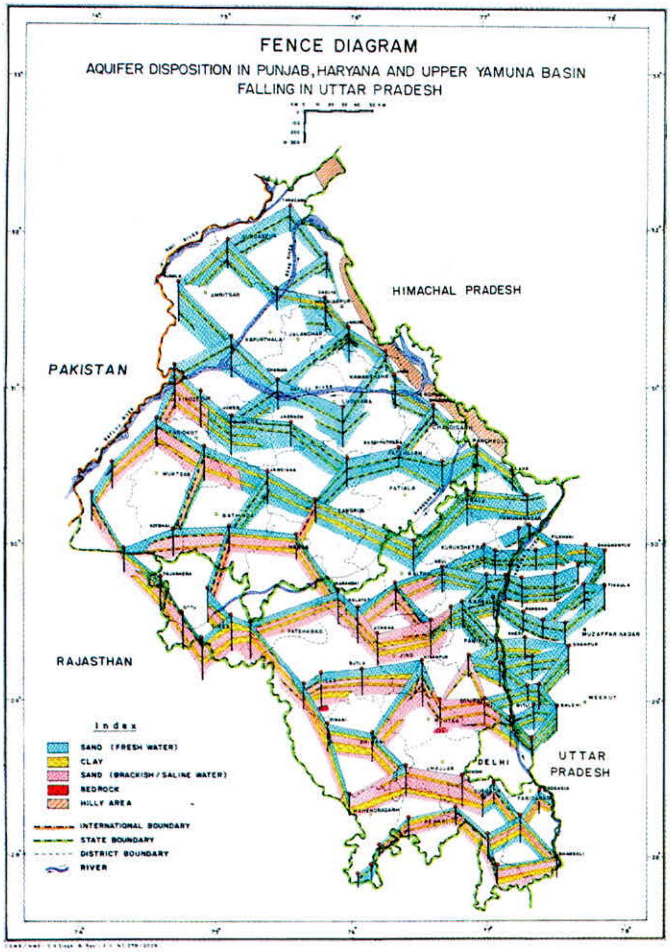

Fig. 1. Aquifer disposition in Punjab, Haryana and Upper Yamuna Basin falling in Uttar Pradesh.

water occurs in quality of ground water. This water gradually deteriorates to sodium bicarbonate type with depth, indicating a base exchange between the cations of ground water and the sub-surface clays. In the groundwater discharge areas the potentiometric head of water in the deeper aquifers have been recorded to be higher than that in the shallow aquifers. Slowly but surely, the inferior quality water leaks upwards as well as laterally to deteriorate the quality of water in shallow aquifers of downstream areas.

It is observed that in the southern part of the States of Punjab, Haryana and UP, fresh water aquifers of limited thickness overlies the brackish to saline water in deeper aquifers. It is evident that the deeper aquifers in alluvial areas are not fully developed in upper reaches and the unutilized ground water in confined aquifers ultimately is lost to the saline aquifers adjacent to the basin boundary. Even though multiple aquifer systems occur in large areas in upper reaches of the river systems, groundwater development is from only shallow phreatic aquifer, which is reflected in the increasing decline in groundwater level. In these areas the deeper aquifer are not developed which is not only under-utilization of resources but also the quality of water deteriorates with time. A large fresh water resource of confined aquifers is ultimately lost to the saline belts. There is a great scope of groundwater development of deeper aquifers in alluvial areas of Punjab, Haryana and Western UP where the confined aquifers have good quality water.

Development of flood plain aquifers: The flood plains in the vicinity of rivers are good repositories of groundwater. A planned management of ground water in the flood plain aquifers offers an excellent scope of its development to meet the additional requirements of water. The development of ground water in Yamuna flood plain area in Delhi is an example of scientific management of water resources. During rainy season, the flood water spreads over the plains but due to very shallow water table the rejected recharge result in river outflows. Central Ground Water Board constructed 95 tubewells in Palla Sector in the depth range of 38-50 m for Delhi Jal Board (Fig. 2). The total pumpage during the pre-monsoon period of 2002 was 40 M.G.D., which created a regional drawdown of about 5 m in the flood plain area. It was observed that immediately after rainy season, the depleted aquifer fully

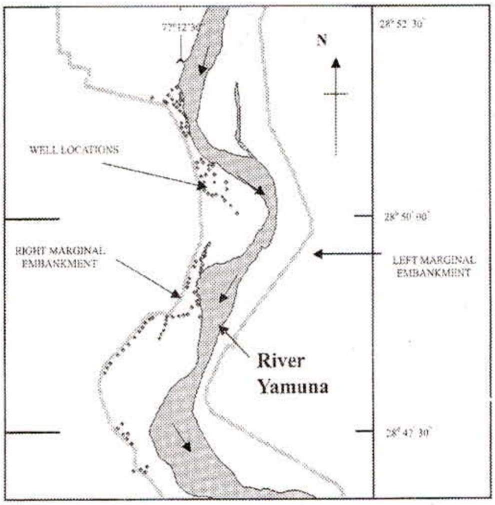

Fig. 2. Groundwater development in Yamuna Flood Plain, Palla Area, Delhi.

recouped. Thus over-development of shallow aquifers in flood plains creates the necessary sub-surface space for augmentation of ground water from the river flows during the monsoon. Induced recharge is an effective management tool to meet the gap of demand and supply in areas adjacent to rivers with active flood plains. A groundwater flow model for the Palla area has been prepared which will be used as a tool for planning future groundwater development in the area so as to maximize the induced recharge. Development of flood plain aquifers is feasible in various parts of the country and should be taken up on a large scale.

Development of ground water in water logged areas: The practice of surface water irrigation without much consideration of groundwater status has often resulted in water logging and soil salinity problems in command areas due to gradual rise in groundwater levels with time. As per the assessment made by the Working Group on Problem Identification in Irrigated Area with Suggested Remedial Measures (1991), about 2.46 mha of the area under surface water irrigation projects is water logged or threatened by water logging. The water logged areas in canal command offer scope for groundwater development by lowering the water table upto six metres or more. The inferior quality of water can be mixed with canal water in a proportion acceptable for irrigation. Thus not only additional water resources for irrigation can be created but also the lowering of water table will help in rainfall recharge in the area, which will help in improvement of soil and water quality.

Development of ground water in areas adjacent to Canal Commands: For an integrated development of surface and ground water one of the effective strategies is to use surface water in one area and utilize the recharge by development of ground water in areas adjacent to canal commands. A case study of Bargi Dam in MP demonstrates the effectiveness of groundwater development in checking water logging in canal command area.

In general, the southern and south-eastern parts of the command area, located adjacent to the main Left Bank Canal (LBC) are poor in groundwater resources with yield of wells varying between 4 and 13 cu.m/hr. for 6 m drawdown (Fig. 3).

However, in the central and the northern parts of the command area, good aquifers occur in the alluvium, which attain thickness of upto 176 metres. In a few pockets adjacent to the river Narmada, tubewells yield upto 360 cum/hr. for 6 m drawdown. The depth to water level is generally shallow along the main LBC but increases northwards and it is more than 25 m below ground level adjacent to Narmada river. Thus, the regional groundwater flow direction is towards river Narmada. A network of branch canals and distributaries are being constructed extending upto river Narmada to achieve the targetted area under surface irrigation. In view of the hydrogeological setup of the area, it is apprehended that with widespread canal irrigation, problems of water logging followed by salinity hazards may crop up in the area in the long run. The advent of surface irrigation may also have a dampening effect on the present development of groundwater resources because of its availability at lower tariffs, thereby indirectly aggravating the water-logging problem in the area. Central Ground Water Board advocates the development of groundwater resources in the central and northern parts of Bargi L.B.C. command (where already good aquifers exist) instead of extending the canal network to this area. This would result not only in a proper utilization of available water resources but also the pumpage from groundwater storage will provide a sub-surface drainage to the areas which are likely to be waterlogged. Thus, conjunctive use of surface water and ground water would help irrigation in large areas without any adverse effect of the uncontrolled surface irrigation.

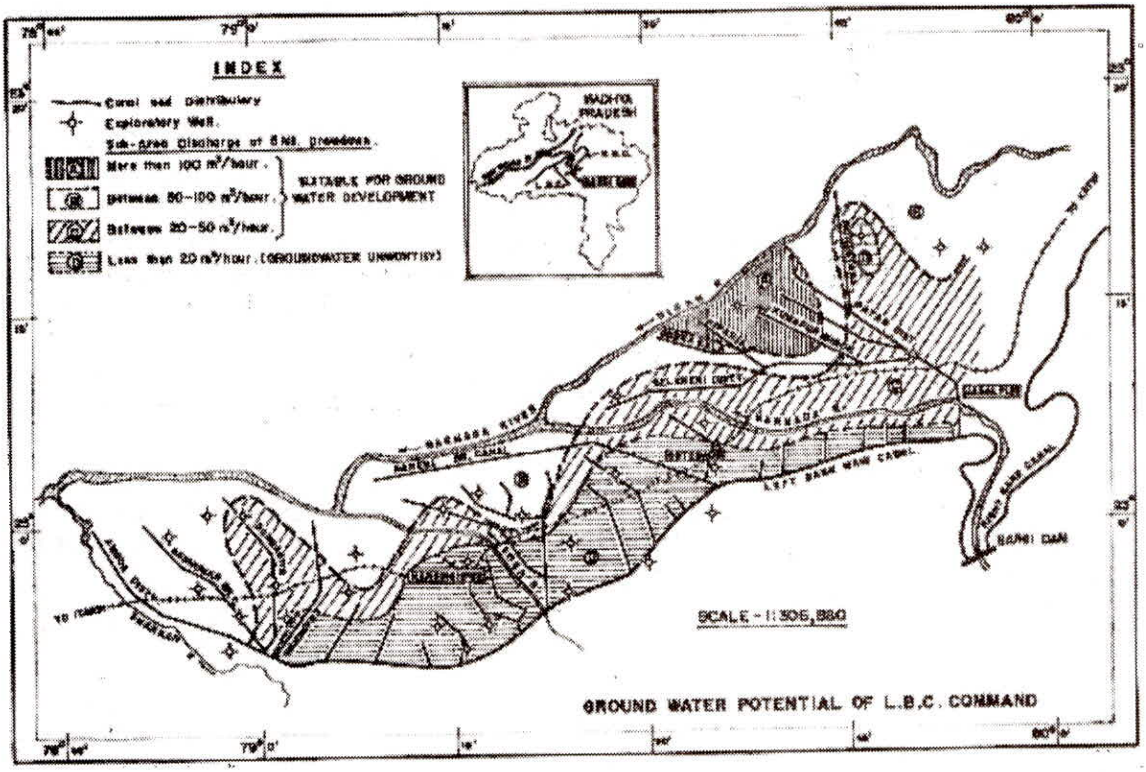

Fig. 3. Groundwater development adjacent to Bargi LBC, MP.

Development of ground water in coastal regions: Ground water in the coastal area occurs under unconfined to confined conditions in wide range of unconsolidated, semi-consolidated and consolidated geological formations. Increasing exploitation and reduction of coastal fresh water outflow upset the dynamic equilibrium in the coastal aquifers. The groundwater salinity in coastal areas can be attributed to several reasons such as inherent salinity, land inundation due to creeks, tidal actions, salt laden winds, irrigation by saline water, upconing and finally the lateral sea water ingress or sea water intrusion. The saline water intrusion is the result of mismanagement of aquifers either due to over-development or due to unscientific way of exploitation. The saline water intrusion carries with it the risks of the matrix of the aquifers getting contaminated, causing a permanent loss to the fresh water storage capacity. Studies carried out by CGWB in the coastal tract of the country have revealed the following acts.

In the state of Kerala the Warkali and Vaikom formations of Tertiary age forms the potential fresh water aquifers. The thickness exceeds 600 m in the central portion of the basin in the Alleppy district, where the basement rock is yet to be encountered. The salinity found in some pockets is because of leaching of salt from the aquifer material (in situ) and not due to sea water ingress. Though, the saline-fresh water interface could not be observed in these prolific aquifers, it should be exploited optimally with a caution and intensive monitoring is required. At the same time there is an urgent need to undertake groundwater modelling in select areas to study the dynamics of saline-fresh water interface, which will ultimately help in scientific development of deeper fresh water in these areas.

In the coastal tract of Gujarat, generally the unconfined aquifer occurs down to depth of 40 m bgl whereas the semi confined to confined conditions are seen between 30 m and 200 m bgl. Due to progressive sea water intrusion the quality of ground water is steadily deteriorating in the coastal facts of Kutch and Saurashtra. In Saurashtra due to topographical gradients the salinity is restricted to certain localized areas within 10 km from the coast. In south Gujarat coast there is very little sea water intrusion because of poorly permeable Deccan traps available in the coast. However the entire coastline of Gujarat is dotted with creeks and under tidal influence almost 4 to 6 kms inland. At places in the vicinity of the coast, because of intense groundwater withdrawal the water table declined to the tune of 3 m below mean sea level, leading to reversal of hydraulic gradient. Hence there is a need of scientific planning for development of these aquifers.

In the state of Tamil Nadu, coastal salinity is quite alarming in certain parts especially in the Minjur area of Thuiruvallur district, it has been observed that the seawater-freshwater interface has moved 2 to 9 km since 1969, the reason could be intensive development of ground water in these areas resulting into sharp decline in groundwater levels and changing the complete hydrodynamics of the area. Further studies in other coastal districts of the country have indicated that the salinity of groundwater is due to inherent reasons in majority of the areas and not due to sea water intrusion. However, detailed studies need to be undertaken to understand the dynamics of saline-fresh water interface so as to plan the development of coastal aquifers on scientific lines and in an optimal manner.

Rainwater Harvesting and Artificial Recharge to Ground Water

Central Ground Water Board has carried out studies to demarcate the areas where decline of groundwater level is on continuous basis and explored the possibility of artificial recharge of aquifers by utilizing the surplus monsoon water runoff. A total of 4.5 lakh sq.km. was identified in the country which need artificial recharge of groundwater. It is estimated that annually about 36.4 BCM of surplus surface runoff can be recharged to augment the groundwater. In rural areas, techniques of artificial recharge by modification of natural movement of surface water through suitable civil structures like Percolation tanks, Check Dams, Nala Bunds, Gully Plugs, Gabion structures, etc. and sub-surface techniques of recharge shaft, well recharge, etc. have been found feasible. The roof top rainwater harvesting is feasible both by augmenting the groundwater storage as well as by storing it in specially built tanks.

The Thar desert of Rajasthan, covering 60% of land area on western side of the State, presents a paradoxical situation of surplus and deficit water areas during short period of monsoon. The Indira Gandhi Nahar Pariyojna (IGNP) is utilizing water from Ravi, Beas and Sutlej rivers for irrigation in Western Thar desert. During monsoon enormous quantity of outflow from Harike Barrage cannot be fully utilized and flows out to Pakistan. The monsoon river flood waters of Ghaggar river is also retained in 19 natural depressions causing water logging problems in the adjoining low lying areas like Baropal, where water level has risen from 50 m bgl to less than 5 m bgl in last one decade. In contrast to this situation of surplus water availability in northern part of the Thar desert, the adjoining districts of Jalore, Sikar, Jhunjhunu and Nagaur are facing alarming decline in groundwater levels and even drinking water is scarce. There is a great scope of transferring the surplus water available for a short period during monsoon to adjacent areas for artificial recharge of fast drying up aquifers. The existing lift irrigation systems (Noher-Sahwa and Gajner lift systems) can be extended to cover adjoining districts of Jhunjhunu, Sikar, Churu, Nagaur and adjoining areas to provide source water for artificial recharge. The augmentation of groundwater resources during the monsoon, through appropriate artificial recharge structures, will go a long way in meeting the water crisis in these water starved areas.

Non-structural Measures

Groundwater resources management requires strategies not only for a scientific development of available resources, but also a focus on need based allocation and pricing of resources, involvement of all stakeholders to understand their problems and needs and effective implementation of regulatory measures after making them aware of available management options. Capacity building of people to undertake necessary changes, if required, and fostering a sense of identity for achievement of goals is key to success.

Ownership of Ground Water

The basic question to be answered before embarking upon various management strategies is about ownership of ground water. The Indian Easement Act 1882 is believed to allow private rights on ground water by viewing it as an easement connected to land. This absolute ownership concept has allowed an unlimited withdrawal of ground water by the owners beneath their land. The consequence of this legal framework is that only land owners can own groundwater in India. Landless individuals and tribals are left out. The over-exploitation of groundwater resources by rich farmers adversely affects the small and marginal farmers whose wells may go dry. A close reading of the relevant portion of clause 7 of the Act may, however, give 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 is an established fact that ground water is a dynamic resource, which flows in defined channels. During pumping of ground water from any abstraction structure the flow pattern is affected. Thus, landowner should have right on water collected/disposed within his land without affecting the normal flow path of ground water. This matter should be taken up at appropriate Government level to ensure the legal position of ground water ownership.

Sectoral Allocation of Ground Water and Pricing

Ground water is a dynamic resource occurring within different hydrogeologically inter-connected systems. Any change in development pattern in one part of the system tends to affect the availability, quality and economics of supplies elsewhere within the system. With the absence of a clearly defined allocation of available resources amongst different user groups there is always a possibility of allegation for causing severe water shortage due to over-exploitation/pollution of ground water by a particular user agency. The controversy of alleged misuse of groundwater by Coca Cola Co. in Kerala is an example. With limited availability of groundwater resource there can be a competition between different user groups to get maximum benefit before it is exhausted. It may result in spiral increase in demands and sharp decrease in the availability. A well thought of mechanism is required to ensure an equitable distribution of available resources with safeguards on their sustainability.

Ground water is an economic good which should be allocated at a cost commensurate with demand amongst various users. Pricing of ground water plays a very important role in increasing the water use efficiency. The present pricing structure of groundwater resources do not provide necessary incentives for efficient use. In agriculture sector, in major part of the country, elective charges are levied on flat rate basis in proportion to the H.P. of the pump used for groundwater extraction. The power supplied to rural areas is generally heavily subsidized, resulting in poor water services at a high cost. The unreliable power supplies encourages farmers to maximize groundwater pumping resulting in over-exploitation of resources. In urban areas also the heavy government subsidies and poor cost recovery contributes to over-exploitation of groundwater. There is an urgent need to formulate policy guidelines for allocation and pricing of ground water used by different sectors.

Regulation of Ground Water Development

As water is a State subject, the management of groundwater resources is a prerogative of concerned State. Ministry of Water Resource has prepared and circulated Model Bills to all the States and Union Territories (latest in 2005). The main thrust is to ensure that all the States have separate State Groundwater Authority for a proper control and regulation of groundwater resources. Andhra Pradesh, Goa, Tamil Nadu, Lakshadweep, Kerala, Pondicherry, Maharashtra and West Bengal have already enacted groundwater legislation Act.

The Central Ground Water Authority, constituted under Environment (Protection) Act of 1986 is playing a key role in regulating and control on development of ground water in over-exploited areas to protect the quantitative as well as qualitative aspects of groundwater availability. For the protection of coastal environment in India, including groundwater resources, a Coastal Regulation Zone Notification (CRZ), 1991 has been enacted. National Coastal Zone Management Authority and State Coastal Zone Management Authorities, constituted under Environment Protection Act (1986) are other legal instruments for overall protection of coastal environment including groundwater.

Stakeholder Participation and Awareness

The participation of stakeholder in groundwater management is key to success of any programme. Private Sector is the major user of groundwater but due to lack of awareness, least initiative is taken in addressing management needs. Private Sector participation is directly linked with the question of cost recovery. A shared understanding of the problems with stakeholder can generate the much needed financial resources and expertise to prove that it is profitable to manage groundwater resources. The participation of stakeholders, especially for rain water harvesting and artificial recharge of groundwater, can be achieved if the role of government is reoriented from provider and financier to facilitator and enabler. Groundwater being a community resource has to be managed by the people. With the increasing scarcity of groundwater, time has come when an integrated planning and management of groundwater resources has to be done with Government and public working hand in hand for a common cause of providing water to all on sustainable basis.

CONCLUSIONS

Groundwater management is a much debated issue but there are very few examples of effective actions on ground. With an unclear status on the ownership of groundwater both at individual and at Government level, an effective regulation of groundwater development is lacking. In the absence of a well defined policy on allocation of groundwater for different user groups and its pricing, a lopsided development results in its over-exploitation. The unscientific development in localized pockets often infringes upon the water availability in adjoining areas and may result in dwindling yields of wells or their getting dry. With little scientific understanding of groundwater occurrence, farmers often resort to construction of deep tubewells in areas where no aquifer exists at depth. The distress areas in peninsular India where farmers enter into debt trap to take extreme step of committing suicides, speaks for the lack of scientific back up. In contrast to this, some alluvial areas in Northern India have multiple aquifer systems having huge reserves of instorage groundwater. The main development of groundwater in these areas is from shallow zones, leading to decline of water levels. The groundwater in confined aquifers at deeper levels is not only under-utilized but also with passage of time it gets deteriorated in its quality. Conjunctive use of surface and groundwater in such alluvial areas of Punjab, Haryana, Uttar Pradesh and Bihar can go a long way in increasing the agriculture production and meet the growing demands of industrial and domestic sectors.

Groundwater resources in the country have to be looked into with a holistic approach and planning for its development has to be done on a scientific basis. For example, the water consuming industries, which do not have any surface water source, should be essentially based in areas with high potential of groundwater availability, irrespective of their geographic location in a State treated as unfavourable due to various other considerations. In areas with shortage of groundwater there is an added need to scientifically manage the available resources. Rainwater harvesting and artificial recharge to groundwater is an important management tool. As pointed out in the paper, even in a water scarce area like Western Rajasthan, surplus water from Harike Barrage for Indira Gandhi Nahar Pariyojna (IGNP) is unutilized for a short period during monsoon resulting in its flow out to Pakistan. This water can be a source water for recharging the aquifers in water starved districts of Jalore, Sikar, Jhujhunu and Nagaur by an extension of lift irrigation systems. Similarly, during monsoons for a short time we often witness floods in Maharashtra and Gujarat in areas otherwise considered groundwater deficit. Scientific schemes have to be drawn to conserve this flood water outflowing to sea during monsoon. In coastal regions the groundwater flow to sea can also be conserved by construction of a battery of injection wells along the coast utilizing the recycled municipal water as source water for recharge. There are a number of options available for effective management of groundwater resources but what we lack is the proper understanding of problems and their likely solutions. The actual implementation of these management options requires a strong infra-structural support both at Central and State level. A strong data base, supported by field oriented R&D studies, is the basic need. A clear policy has to be formulated on the role of Central and State agencies in creating scientific data base. Both at Central and State levels the subject of groundwater is covered under different departments dealing with drinking water, agriculture, irrigation, pollution and environment, with very little control on their programmes and activities.

An effective management of groundwater resources requires an integrated approach in both planning and implementation of schemes. Central Government agencies should coordinate and bring out policies on scientific considerations for effective management of groundwater resources and provide the necessary guidelines for successful implementation. There is a greater responsibility for Central agencies to carry out system analysis essential for management. The R&D studies, supported by mathematical models, defining the behaviour of groundwater systems under different stress, can provide a scientific base for States to crystallize these findings on ground. There is an urgent need in each State to enhance the scientific capabilities of their organizations to address in right earnest the various issues of groundwater management. Without an effective institutional mechanism the targets for sustainable management of groundwater cannot be achieved. States have to first understand the emerging challenges and work out solutions which can help in providing water to people in the best way at least cost and on a sustainable basis. Groundwater being a community resource requires an active public participation. With increasing scarcity of groundwater the time has come when Government and Public should work hand in hand for an integrated management targetted towards providing water to all on a sustainable basis.

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Annexure I

Categorization of Blocks/Mandals/Talukas in India

Sl.No.	*States/Union Territories*	*Total No. of Assessed Units*	*Safe*		*Semi-critical*		*Critical*		*Over-exploited*		*Remarks*
			Nos.	*%*	*Nos.*	*%*	*Nos.*	*%*	*Nos.*	*%*	
	States										
1	Andhra Pradesh	1231	760	62	175	14	77	6	219	18	-
2	Arunachal Pradesh	13	13	100	0	0	0	0	0	0	-
3	Assam	23	23	100	0	0	0	0	0	0	-
4	Bihar	515	515	100	0	0	0	0	0	0	-
5	Chattisgarh	146	138	95	8	5	0	0	0	0	-
6	Delhi	9	2	22	0	0	0	0	7	78	-
7	Goa	11	11	100	0	0	0	0	0	0	-
8	Gujarat	223	97	43	69	31	12	5	31	14	Rest 14 talukas- Saline
9	Haryana	113	42	37	5	4	11	10	55	49	-
10	Himachal Pradesh	5	5	100	0	0	0	0	0	0	-
11	Jammu & Kashmir	8	8	100	0	0	0	0	0	0	-
12	Jharkhand	208	208	100	0	0	0	0	0	0	-
13	Karnataka	175	93	53	14	8	3	2	65	37	-
14	Kerala	151	101	67	30	20	15	10	5	3	-
15	Madhya Pradesh	312	264	85	19	6	5	2	24	8	-
16	Maharashtra	318	287	90	23	7	1	0	7	2	-
17	Manipur	7	7	100	0	0	0	0	0	0	-
18	Meghalaya	7	7	100	0	0	0	0	0	0	-
19	Mizoram	22	22	100	0	0	0	0	0	0	-
20	Nagaland	7	7	100	0	0	0	0	0	0	-
21	Orissa	314	308	98	0	0	0	0	0	0	Rest 6 blocks- Saline
22	Punjab	137	25	18	4	3	5	4	103	75	-
23	Rajasthan	237	32	14	14	6	50	21	140	59	Rest 1 block- Saline
24	Sikkim	1	1	100	0	0	0	0	0	0	-
25	Tamil Nadu	385	145	38	57	15	33	9	142	37	Rest 8 blocks- Saline
26	Tripura	38	38	100	0	0	0	0	0	0	-
27	Uttar Pradesh	803	665	83	88	11	13	2	37	5	-

(Contd.)

Annexure I *(Contd.)*

Sl.No.	*States/Union Territories*	*Total No. of Assessed Units*	*Safe*		*Semi-critical*		*Critical*		*Over-exploited*		*Remarks*
			Nos.	*%*	*Nos.*	*%*	*Nos.*	*%*	*Nos.*	*%*	
28	Uttaranchal	17	12	71	3	18	0	0	2	12	-
29	West Bengal	269	231	86	37	14	1	0	0	0	-
	Total States	**5705**	**4067**	**71**	**546**	**10**	**226**	**4**	**837**	**15**	-
	Union Territories										
1	Andaman & Nicobar	1	1	100	0	0	0	0	0	0	-
2	Chandigarh	1	1	100	0	0	0	0	0	0	-
3	Dadra & Nagar Haveli	1	1	100	0	0	0	0	0	0	-
4	Daman & Diu	2	0	0	1	50	0	0	1	50	-
5	Lakshadweep	9	6	67	3	33	0	0	0	0	-
6	Pondicherry	4	2	50	0	0	0	0	1	25	Rest 1 Region- Saline
	Total Uts	**18**	**11**	**61**	**4**	**22**	**0**	**0**	**2**	**11**	-
	Grand Total	**5723**	**4078**	**71**	**550**	**10**	**226**	**4**	**839**	**15**	-

Note: **Blocks** - Bihar, Chhattisgarh, Haryana, Jharkhand, Kerala, Madhya Pradesh, Manipur, Mizoram, Orissa, Punjab, Rajasthan, Tamilnadu, Tripura, Uttar Pradesh, Uttaranchal, West Bengal

Mandals (command/ non-command) - Andhra Pradesh

Talukas - Goa, Gujarat, Karnataka, Maharashtra

Districts - Arunachal Pradesh, Assam, Delhi, Meghalaya, Nagaland

Districts (Valley) - Himachal Pradesh, Jammu & Kashmir

State - Sikkim

Islands - Lakshadweep

UT - Andaman & Nicobar, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Pondicherry

Annexure II

State-wise Groundwater Resources Availability, Utilization and Stage of Development, India

Sl. No.	States/Union Territories	Annual Replenishable Groundwater Resource					Natural Discharge during non-monsoon seasons	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future irrigation	Stage of Ground water Development (%)
		Monsoon Season		Non-monsoon Season		Total			Irrigation	Domestic and industrial uses	Total			
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	States													
1	Andhra Pradesh	16.04	8.93	4.20	7.33	36.50	3.55	32.95	13.88	1.02	14.90	2.67	17.65	45
2	Arunachal Pradesh	1.57	0.00009	0.98	0.0002	2.56	0.26	2.30	0.0008	0	0.0008	0.009	2.29	0.04
3	Assam	23.65	1.99	1.05	0.54	27.23	2.34	24.89	4.85	0.59	5.44	0.98	19.06	22
4	Bihar	19.45	3.96	3.42	2.36	29.19	1.77	27.42	9.39	1.37	10.77	2.14	15.89	39
5	Chattisgarh	12.08	0.43	1.30	1.13	14.93	1.25	13.68	2.31	0.48	2.80	0.70	10.67	20
6	Delhi	0.13	0.06	0.02	0.09	0.30	0.02	0.28	0.20	0.28	0.48	0.57	0.00	170
7	Goa	0.22	0.01	0.01	0.04	0.28	0.02	0.27	0.04	0.03	0.07	0.04	0.18	27
8	Gujarat	10.59	2.08	0.00	3.15	15.81	0.79	15.02	10.49	0.99	11.49	1.48	3.05	76
9	Haryana	3.52	2.15	0.92	2.72	9.31	0.68	8.63	9.10	0.35	9.45	0.60	-1.07	109
10	Himachal Pradesh	0.33	0.01	0.08	0.02	0.43	0.04	0.39	0.09	0.02	0.12	0.04	0.25	30
11	Jammu & Kashmir	0.61	0.77	1.00	0.32	2.70	0.27	2.43	0.10	0.24	0.33	0.42	1.92	14
12	Jharkhand	4.26	0.14	1.00	0.18	5.58	0.33	5.25	0.70	0.38	1.09	0.56	3.99	21
13	Karnataka	8.17	4.01	1.50	2.25	15.93	0.63	15.30	9.75	0.97	10.71	1.41	6.48	70
14	Kerala	3.79	0.01	1.93	1.11	6.84	0.61	6.23	1.82	1.10	2.92	1.40	3.07	47
15	Madhya Pradesh	30.59	0.96	0.05	5.59	37.19	1.86	35.33	16.08	1.04	17.12	1.74	17.51	48
16	Maharashtra	20.15	2.51	1.94	8.36	32.96	1.75	31.21	14.24	0.85	15.09	1.52	16.10	48
17	Manipur	0.20	0.005	0.16	0.01	0.38	0.04	0.34	0.002	0.0005	0.002	0.02	0.31	0.65
18	Meghalaya	0.79	0.03	0.33	0.005	1.15	0.12	1.04	0.00	0.002	0.002	0.10	0.94	0.18
19	Mizoram	0.03	0.00	0.02	0.00	0.04	0.004	0.04	0.00	0.0004	0.0004	0.0008	0.04	0.90
20	Nagaland	0.28	0.00	0.08	0.00	0.36	0.04	0.32	0.00	0.009	0.009	0.03	0.30	3
21	Orissa	12.81	3.56	3.58	3.14	23.09	2.08	21.01	3.01	0.84	3.85	1.22	16.78	18
22	Punjab	5.98	10.91	1.36	5.54	23.78	2.33	21.44	30.34	0.83	31.16	1.00	-9.89	145
23	Rajasthan	8.76	0.62	0.26	1.92	11.56	1.18	10.38	11.60	1.39	12.99	2.72	-3.94	125
24	Sikkim	-	-	-	-	0.08	0.00	0.08	0.00	0.01	0.01	0.02	0.05	16
25	Tamil Nadu	4.91	11.96	4.53	1.67	23.07	2.31	20.76	16.77	0.88	17.65	0.91	3.08	85
26	Tripura	1.10	0.00	0.92	0.17	2.19	0.22	1.97	0.08	0.09	0.17	0.20	1.69	9
27	Uttar Pradesh	38.63	11.95	5.64	20.14	76.35	6.17	70.18	45.36	3.42	48.78	5.30	19.52	70
28	Uttaranchal	1.37	0.27	0.12	0.51	2.27	0.17	2.10	1.34	0.05	1.39	0.08	0.68	66
29	West Bengal	17.87	2.19	5.44	4.86	30.36	2.90	27.46	10.84	0.81	11.65	1.24	15.32	42
	Total States	**247.88**	**69.51**	**41.83**	**73.15**	**432.42**	**33.73**	**398.70**	**212.38**	**18.04**	**230.44**	**29.12**	**161.92**	**58**
	Union Territories													
1	Andaman & Nicobar	-	-	-	-	0.330	0.005	0.320	0.000	0.010	0.010	0.008	0.303	4
2	Chandigarh	0.016	0.001	0.005	0.001	0.023	0.002	0.020	0.000	0.000	0.000	0.000	0.020	0
3	Dadra & Nagar Haveli	0.059	0.005			0.063	0.003	0.060	0.001	0.007	0.009	0.008	0.051	14
4	Daman & Diu	0.006	0.002	0.000	0.001	0.009	0.0004	0.008	0.007	0.002	0.009	0.003	-0.002	107
5	Lakshadweep	-	-	-	-	0.012	0.009	0.004	0.000	0.002	0.002	-	-	63
6	Pondicherry	0.057	0.067	0.007	0.029	0.160	0.016	0.144	0.121	0.030	0.151	0.031	-0.008	105
	Total UTs	**0.138**	**0.075**	**0.012**	**0.031**	**0.597**	**0.036**	**0.556**	**0.129**	**0.051**	**0.181**	**0.050**	**0.365**	**33**
	Grand Total	**248.01**	**69.59**	**41.85**	**73.19**	**433.02**	**33.77**	**399.25**	**212.51**	**18.09**	**230.62**	**29.17**	**162.29**	**58**

Annexure III

Estimates of Static Fresh Groundwater Resources of India

Sl. No.	*State*	*Fresh Groundwater Resources*		
		Alluvium/ Unconsolidated rocks (mham.)	*Hard Rocks (mham.)*	*Total (mham.)*
1.	Andhra Pradesh	7.6	2.6	10.2
2.	Assam	92.0	—	92.0
3.	Bihar	255.7	1.1	256.8
4.	Gujarat	9.2	1.2	10.4
5.	Haryana	4 2.0	0.1	42.1
6.	Himachal Pradesh	1.3	—	1.3
7.	Jammu & Kashmir	3.5	—	3.5
8.	Karnataka	—	1.7	1.7
9.	Kerala	0.5	0.6	1.1
10.	Madhya Pradesh	1.4	2.7	4.1
11.	Maharashtra	1.6	2.2	3.8
12.	Orissa	16.2	1.3	17.5
13.	Punjab	91.0	—	91.0
14.	Rajasthan	11.5	1.3	12.8
15.	Tamil Nadu	9.8	—	9.8
16.	Tripura	10.1	—	10.1
17.	Uttar Pradesh	347.0	3.0	350.0
18.	West Bengal	162.5	0.1	162.6
19.	Delhi	0.3	—	0.3
20.	Chandigarh	0.1	—	0.1
	Total	1063.3	17.9	1081.2

Note: 1. The estimates are for the aquifer zones below the zone of water table.
2. In-storage groundwater resource = volume of aquifer zones × specific yield.