Towards Better Management of Ground Water Resources in India

B.M.Jha, Chairman & S.K.Sinha, Scientist D
Central Ground Water Board
Bhujal Bhawan, CGO Complex, NH IV, Faridabad- 121 001, Haryana, India.
e-mail: chmn-cgwb@nic.in

Abstract

Groundwater is the most preferred source of water in various user sectors in India on account of its near universal availability, dependability and low capital cost. The increasing dependence on ground water as a reliable source of water has resulted in indiscriminate extraction in various parts of the country without due regard to the recharging capacities of aquifers and other environmental factors. On the other hand, there are areas in the country, where ground water development is sub-optimal in spite of the availability of sufficient resources, and canal command areas suffering from problems of water logging and soil salinity due to the gradual rise in ground water levels. As per the latest assessment, the annual replenishable ground water resource of country has been estimated as 433 billion cubic meter (bcm), out of which 399 bcm is considered to be available for development for various uses. The irrigation sector remains the major consumer of ground water, accounting for 92% of its annual withdrawal. The development of ground water in the country is highly uneven and shows considerable variations from place to place. Though the overall stage of ground water development is about 58%, the average stage of ground water development in North Western Plain States is much higher (98%) when compared to the Eastern Plain States (43%) and Central Plain States (42%). Management of ground water resources in the Indian context is an extremely complex proposition. The highly uneven distribution and its utilization make it impossible to have single management strategy for the country as a whole. Any strategy for scientific management of ground water resources should involve a combination of supply side and demand side measures depending on the regional setting.

As far as ground water resource availability is concerned the share of alluvial areas covering Eastern Plain states of Bihar, Orissa (part), Eastern Uttar Pradesh and West Bengal and North Western plain states of Delhi, Haryana, Punjab, Western Uttar Pradesh, Chandigarh; is about 44% of the total available resource. However, these groups of states have overall development of the order of 43% and 98% respectively. In view of the marked difference in stage of ground water in these areas, there is a need to critically analyze the underlying factors responsible for the imbalances in terms of technical and socio-economic considerations. These should also be taken for consideration while formulating any comprehensive water resources management initiatives for the country. There is urgent need for coordinated efforts by various Governments and non-governmental agencies, social service organizations and the stakeholders for evolving implementable plan for effective management of this precious natural resource.

1. Introduction:

Groundwater has emerged as the primary democratic water source and poverty reduction tool in India's rural areas. On account of its near universal availability, dependability and low capital cost, it is the most preferred source of water to meet the requirements of various user sectors in India. Ground water has made significant contributions to the growth of India's Economy and has been an important catalyst for its socio economic development. 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 capacities of aquifers and other environmental factors.

The unplanned and non-scientific 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 at low-key in spite of the availability of sufficient resources, similarly the canal command areas suffer from problems of water logging and soil salinity due to the gradual rise in ground water levels.

In order to address various issues related to ground water, keeping in view the climatic change, there is a need to prepare a comprehensive road map with identified strategies for scientific and sustainable management of the available ground water resources in the country so as to avert the looming water crisis. In addition to addressing the issues of declining water level, the strategies should also focus on the imbalances in ground water development in the country, reasons thereof and suggesting measures including accelerated development of ground water in areas with low stage of ground water development.

2. Hydrogeological Set –up of the Country:

India is a vast country with a highly diversified hydrogeologic set-up. The ground water behavior 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. The rock formations range in age from Archaean to Quaternary-Recent period. The Archaean rocks are present in the southern states where as the recent sediments are confined to Indo-Gangetic alluvial plains. The major Geological Formations are the –

1) Consolidated formations represented by Igneous & Metamorphic rocks with major rock types consisting of granites, Charnockites, Quartzites & associated Phyllite, slate etc; basalts & associated igneous rocks.
2) The semi consolidated rock formations are represented by rocks of Mesozoic & tertiary period with major rock types represented by limestone, sandstone, pebbles & boulder conglomerates.
3) The unconsolidated formations belong to Pleistocene to recent period & represented by major rocks such as boulders, pebbles, different grade of sands, silt-clay. These rocks form the major potential aquifer zones.

The Indian sub continent is occupied by major geological rock types such as metamorphics of pre Cambrian period, Igneous rocks represented by basaltic rocks of Cretaceous-Eocene period, Gondwana & Vindhyan rocks which are overlain by quaternary to recent sedimentary deposits .The distribution of these rock types are given in geological map (Figure 1).

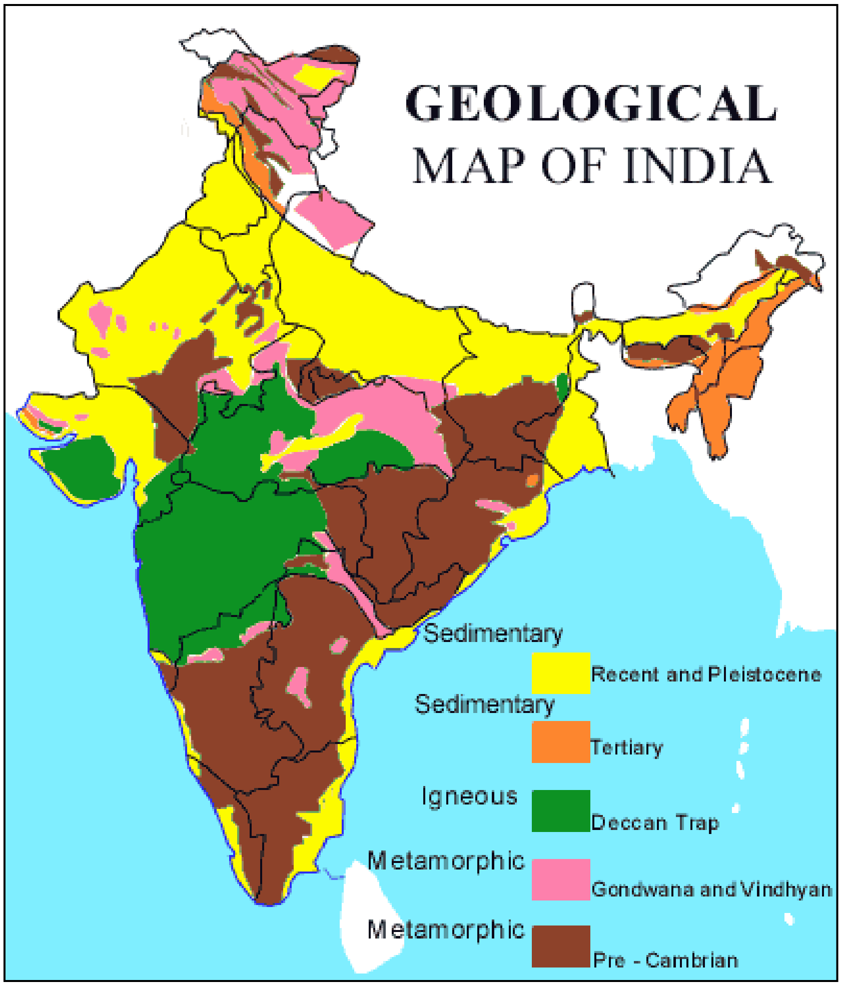
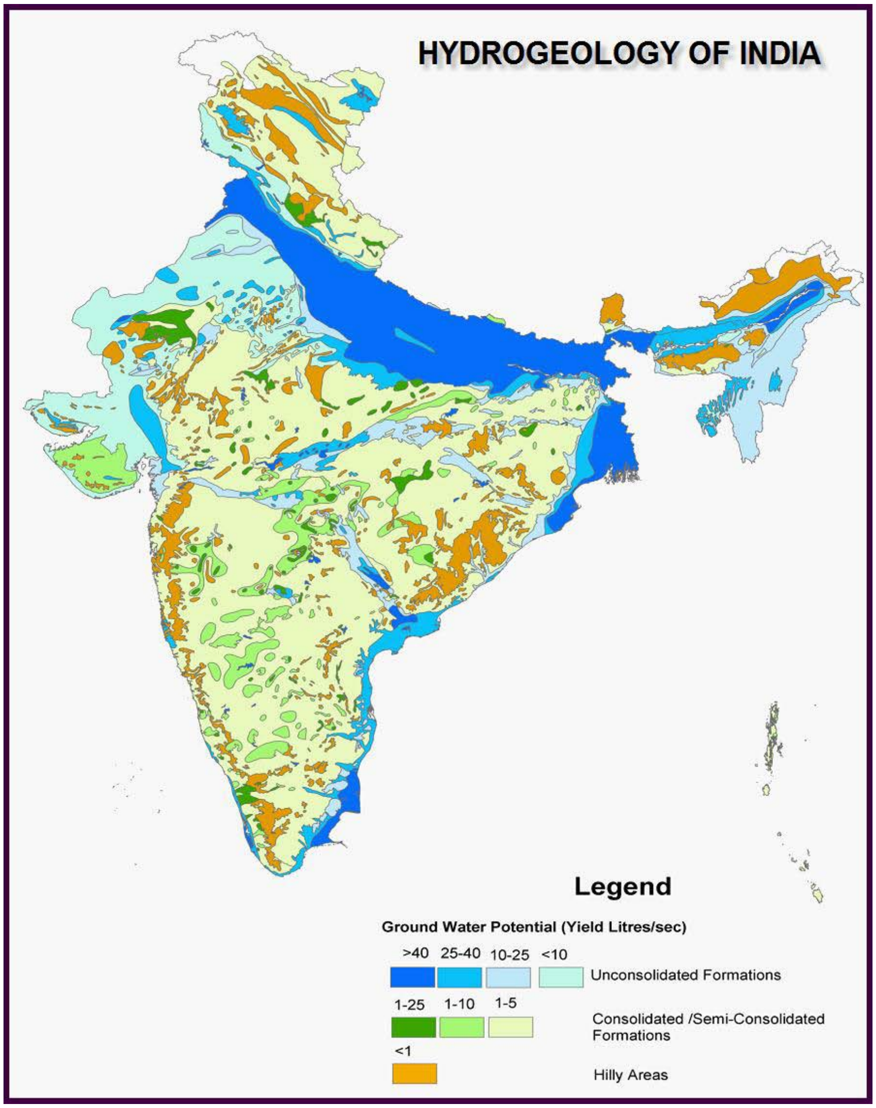


Figure 1 : Geological Map of India (Source: GSI)

Based on the formation characteristics and hydraulic properties to store and transmit ground water hydrogeologically all the litho units can be placed under two broad groups of water bearing formations Viz. ***Porous Formations*** which can be further classified into unconsolidated and semi consolidated formations having the primary porosity and ***Fissured Formation* or Consolidated** formations which has mostly the secondary or derived porosity. The Hydrogeological map showing the broad group of consolidated and unconsolidated water bearing formations along with their yield prospects are shown in F**ig.2**.

Physiographic and geomorphologic settings are among the important factors that control the occurrence and distribution of ground water. Based on these factors, the country has been broadly divided into five distinct regions as below:



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 underlain mostly by rocks such as granites, slate, sandstone and lime stone ranging in age from Paleozoic to Cenozoic. The yield potential ranges from 1 to 40 lps. Though this area offers very little scope for groundwater storage, it acts 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, accounting for more than one fourth of country's land area, comprises the vast plains of *Ganges* and *Brahmaputra* rivers and are underlain by thick piles of sediments of Tertiary and Quaternary age. This vast and thick alluvial fill, exceeding 1000 m at places, constitute the most potential and productive ground water reservoir in the country. These are characterized by regionally extensive and highly productive multi-aquifer systems. The ground water development in this region is still sub-optimal, except 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 yield ranging from 25-50 lps.

iii) **Peninsular Shield Area**: 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, and Tamil Nadu, Andhra Pradesh, Orissa and Kerala. 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 30m 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 50m, occasionally down to 100m, 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 Area**: Coastal areas have a thick cover of alluvial deposits of Pleistocene to Recent age and form potential multi-aquifer systems in the states of Gujarat, Kerala, 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, the ground water over-development in these areas entails the risk of saline water ingress. Ground water prospects in these aquifers vary widely depending on the local conditions and may range from 5-25 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 various purposes. The yield potential of the wells varies from 1-10 lps.

3. Ground Water Resources Availability:

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 ground water withdrawal takes place from the upper unconfined aquifers, which are also the active recharge zones and holds the replenishable ground water resource. The replenishable ground water resource in the active recharge zone in the country has been assessed by Central Ground Water Board jointly with the concerned State Government authorities. The assessment was carried out with Block/Mandal/Taluka/Watershed as the unit and as per norms recommended by the Ground Water Estimation Committee (GEC)-1997. As per the latest assessment, the annual replenishable ground water resource in this zone has been estimated as 432 billion cubic meter (bcm), out of which 399 bcm is considered to be available for development for various uses after keeping 34 bcm for natural discharge during non-monsoon period for maintaining flows in springs, rivers and streams (Central Ground Water Board, 2006).

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. The ground water draft for the country as a whole has been estimated as 231 bcm (Central Ground Water Board, 2006), about 92 percent of which is utilized for irrigation and the remaining 8 percent for domestic and industrial uses. Hence, the stage of ground water development, computed as the ratio of ground water draft to total replenishable resource, 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.

As a part of the resource estimation following the GEC 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 (14.7 %) 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 (3.9 %), which have been categorized as 'Critical'. 550 assessment units with stage of ground water development in the range of 70 to 100 % and long-term decline of water levels either during pre- or post-monsoon period have been categorized as 'Semi-Critical' and 4078 assessment units with stage of ground water development below 70% have been categorized as 'Safe'. 30 assessment units have been excluded from the assessment due to the salinity of ground water in the aquifers in the replenishable zone. Salient details of ground water resource availability, utilization, stage of development and categorization of assessment units for the above Regions of the country is given in **Table.1 and** geographic distribution of various categories of assessment units is shown in **Fig.3.**

In addition to the resources available in the zone of water level fluctuation, extensive ground water resources have been proven to occur in the deeper confined aquifers in the country, a major chunk of which is in the Ganga-Brahmaputra alluvial plains (Romani, 2006). Such resources are also available in the deltaic and coastal aquifers to a lesser extent. 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'. The quantum of these resources has been tentatively estimated as ~10,800 bcm. Though the ground water resources in these aquifers are being exploited to a limited extent in parts of Punjab, Haryana and western Uttar Pradesh, detailed studies are to be taken up to fully understand the yield potentials and characteristics of these aquifers.

Table.1. Ground Water Resources Availability and Status of its Utilization in India

S. No	Regions	Annual Replenishable Ground Water Resource (bcm)	Natural Discharge during non-monsoon season (bcm)	Net Annual Ground Water Available (bcm)	Annual Ground Water Draft (bcm)	Stage of Ground Water Developmen t (%)	Categorization of Assessment Units (Blocks / Mandals)		
							Total Assessment Units	Over Exploited, Nos / %	Critical Nos / %
1	2	3	4	5	6	7	8	9	10
1	Northern Himalayan states	5.4	0.48	4.92	1.84	37	30	2 / 6.67	0
2	North Eastern Hilly States	33.99	3.02	30.98	5.63	18	118	0/0	0
3	Eastern Plain States	111.63	9.03	102.5	43.97	43	1895	1/ .05	2/.11
4	North Western Plain States	80.78	6.92	73.85	72.17	98	277	201/72.56	28/10.11
5	Western arid Region	27.38	1.97	25.4	24.48	96	462	172/37.23	62/13.42
6	Central Plateau States	90.723	5.19	85.53	36.11	42	985	31/3.15	6/.61
7	Southern Peninsular States	82.78	7.14	75.65	46.4	61	1946	432/22.2	128/6.58
8	Islands	0.34	0.01	0.32	0.01	4	10	0	0
	Country Total	**433.02**	**33.77**	**399.26**	**230.63**	**58**	**5723**	**839**	**226**

Note:

<u>*Southern peninsular states*</u> – Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry; <u>*North Eastern hilly states*</u> – Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura; Eastern plain states – Bihar, Orissa (part) , Eastern Uttar Pradesh and West Bengal; <u>*Central Plateau states*</u> – Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Dadra & Nagar Haveli; <u>*North Western plain states*</u> – Delhi, Haryana, Punjab, Western Uttar Pradesh, Chandigarh; <u>*Western arid states*</u> – Gujarat, Rajasthan, Daman & Diu; <u>*Northern Himalayan states*</u> – Himachal Pradesh, Jammu & Kashmir, Uttarakhand; <u>*Islands*</u> – Andaman & Nicobar, Lakshadweep.

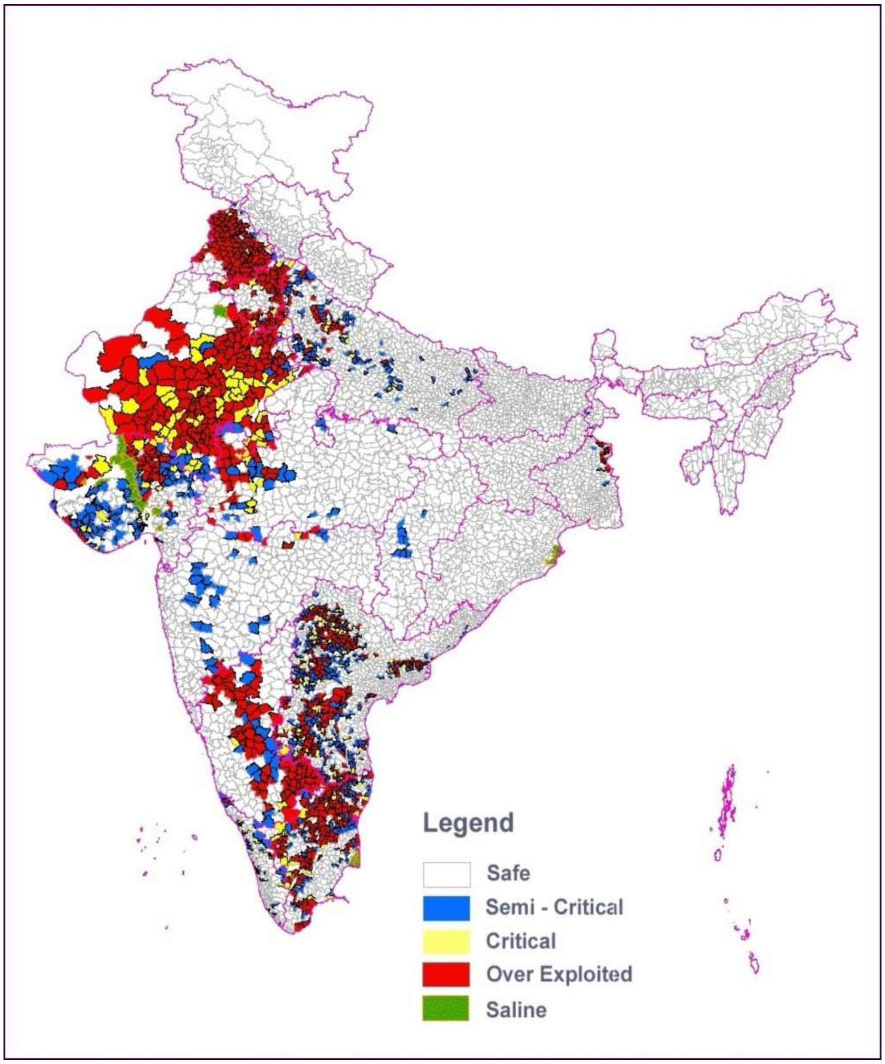


Fig.3 Geographical Distribution of Various Categories of Assessment Units in India

4. Management of Ground Water Resources:

Management of ground water resources in the Indian context 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.

A) Supply Side Measures

As already mentioned, these measures are aimed at increasing the ground water 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 additional ground water resources through suitable means and augmentation of the ground water resources through artificial recharge and rainwater harvesting 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.

(i) Scientific Development of Ground Water Resources

a) Ground Water Development in Alluvial Plains:

b) Ground Water Development in Coastal Areas:

c) Ground Water Development in Hard Rock Area

d) Ground Water Development in Water-logged Areas

e) Development of Flood Plain Aquifers

(ii) Rainwater Harvesting and Artificial Recharge

B) 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 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.

5. Groundwater Development Prospects in India:

The analysis of available data indicates that contribution made by ground water to the agricultural economy of India has grown steadily since early 1970's. In just last two decades, the ground water irrigated lands in India has increased by nearly 105%, this change was most striking in northern India, the heart of the Green Revolution.

A close examination of the ground water resource availability in different geomorphological terrains of the country and its utilization as presented in Table 1, indicates that out of the total of 433 BCM of annual replenishable ground water resources available in the country , the share of alluvial areas covering Eastern Plain states of Bihar, Orissa (part) , Eastern Uttar Pradesh and West Bengal; *and* North Western plain states of Delhi, Haryana, Punjab, Western Uttar Pradesh, Chandigarh; is about 192 BCM which is works out to be 44% of the total available resource. The enigma is in the eastern plain states the overall stage of ground water development is about 43%, whereas the overall stage of ground water development in North Western Plain states covering Punjab, Delhi and Haryana is 98%. Except Western part of Uttar Pradesh, a major part of the area is overexploited.

A perusal of statistics of the increase in the number of mechanized wells and tube wells also illustrates how quickly ground water irrigation has spread. Number of wells rocketed in the last 40 years from less than one million to more than 19 million in the year 2000 itself as per the last census record. Further, the ground water irrigation has greater impact in poverty alleviation, as in relation to the amount of land they cultivate, poor farmers are better represented than richer farmers in their use of ground water. Small and marginal farmers (less than 2 Hectares land) make up only 20% of the total agricultural area. Yet these small farmers account for 38% of the net area irrigated by wells and 35% of the tube wells fitted with electrical pump sets.

Probably, the time has come to focus our attention on analyzing the imbalances on the use of ground water. There is no doubt that overuse of ground water is occurring in isolated areas, and it can have devastating effects on communities. This leads to two burning questions about ground water overexploitation, why are some areas affected and not others? How can be it be pre determined or predicted? The answer becomes clear when one key point is understood: ground water use is dependent on Demand, not Supply. The fact that ground water is tapped only where there are large aquifers, or a lot of rainfall or surface irrigation systems exists – which results in more recharge to ground water may not be true in strict sense. This can be very well visualized from the fact that in spite of abundance of ground water resources, the utilization in the Eastern Plain states of Bihar, West Bengal is much less as compared to Punjab and Haryana. This proves the fact that ground water use is purely Demand driven. There might have been several reasons for less demand of water in the eastern states, but the fact remains that, there is ample scope of ground water development in these areas so as to balance the ground water use of country.

Hence, there is an urgent need to have a comprehensive accelerated ground water development plan for the areas having low stage of development and further scope for ground water development which should go parallel with the measures for ground water augmentation. The ground water governance must include the supply side management

5.1 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 replenishable 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 unforeseen situations during cyclonic disasters as well as Tsunamis.

5.2 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.

5.3 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.

5.4 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 to 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 downstream. 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 level. 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.

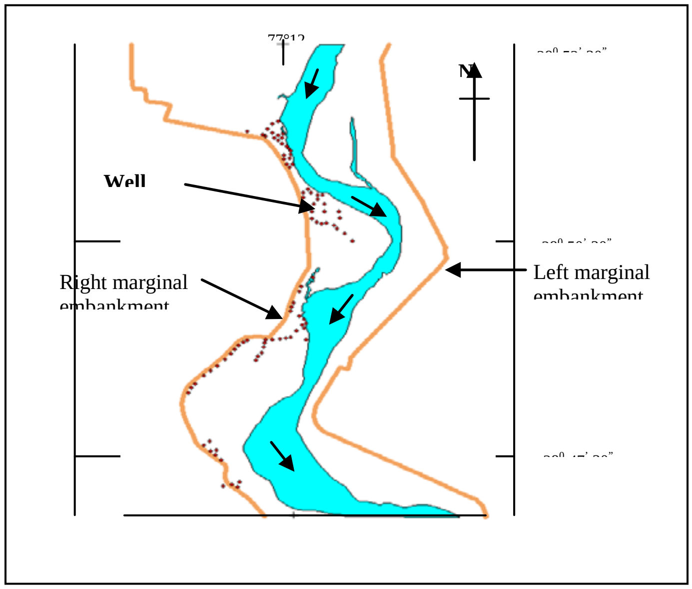


Fig. 4 Ground Water Development in Yamuna flood plain, Palla sector, Delhi

A study in this regard was taken up in northern part of Yamuna flood plain area in Delhi (Fig.4) 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 (NIH & CGWB, 2006). 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 ground water development prospects of the flood plains involving stream-aquifer interaction.

5.5 Alluvial Areas (Indo Gangetic 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 developments 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 replenishable 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 the prorate basis up-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, 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 befitting options for optimal utilization of these resources.

5.6 Rainwater Harvesting and Artificial Recharge:

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. Need, suitability of area in terms of availability of sub-surface storage space and availability of surplus monsoon run-off is 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.

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.

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. 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.

6. 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.

6.1 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. Based on data thus generated, vulnerable areas are notified for the purpose of ground water regulation. 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. Ministry of Water resources has prepared and circulated Model Bills to all States and Union Territories during 2005. The main thrust of these bills 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. 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.

In the present paper an attempt has been made to present the ground water development scenario and ground water development prospects in the Indo Gangetic plain taking the case studies of the State of Bihar, Punjab and West Bengal.

6. Prospects of Groundwater Development in Indo-Gangetic Plains:

7.1 Bihar

Bihar is undergoing fast economic development with its impact on life style, natural resources and environment. But economic growth has persisting inadequacies. One such challenging area is agriculture, which has the key role in poverty alleviation in Bihar, where 90% population is rural. Though the state is bestowed with water and land, the state needs to substantially increase the cropping intensity and also the irrigation intensity. Assured availability of water for drinking, agriculture and industries are the key factors to determine the future economic scenario. During the last six decades, the remarkable feature in irrigation development is the conspicuous growth in the use of groundwater. However, in Bihar at present, the groundwater meets the irrigation to only about 65 % of the gross irrigated area. It has affected the agricultural production for want of irrigations. The major credit for increase in groundwater use goes to a large extent to the farmers’ own investment and spread of groundwater market. There are about 0.9 million shallow and about 1700 deep tube wells in operation in the state. Besides, ground water caters the entire domestic water supply for ~ 8.3 Crore population. Even then, the stage of groundwater development is only 39%. To enhance the irrigation potential ground water can safely be developed at least to the level of 60-70% as groundwater irrigation is under the direct control of the farmers and is amenable to precision agriculture and higher irrigation efficiency (Sharma, 2009). It is essential particularly in the North Bihar Plain which gives tremendous scope owing to conducive hydrogeological condition and shallow water level. While in the South Bihar Plain, along with the development of groundwater it is necessary that the artificial recharge schemes are implemented. In this regard the status of groundwater development is discussed below.

7.1.1 Ground Water Development Status

Bihar, with 94,163 sq.km area is one of the densely populated states of India with an average population density of 880 persons/sq km, compared to countrywide average of 325 persons/sq km (2001 census). Only 10% of the total population is urban. About 90% geographical area of the state is underlain by Gangetic alluvium brought down by the river Ganga and its Himalayan and peninsular tributaries. The remaining area exhibits piedmont surface and undulating hills of Chhota Nagpur granite gneiss of Precambrian age and Vindhyan Super group. The Rajmahal Trap of Cenozoic age covers a narrow track in the extreme south-eastern part of the state. The alluvial plain is divided into two broad units, the north Ganga Plain covering the area north of the course of Ganga, where 17 districts are located. The alluvial plain between river Ganga and undulating hard rock terrain in south is denoted as South Ganga Plain where 21 districts are located either in full or in parts. The Ganga plain exhibits a flat monotonous terrain dotted with fluvial geomorphic landform.

The normal annual rainfall of the state is 1176 mm with an average number of 45 rainy days. About 85% of the total rainfall occurs during monsoon months. There is a pattern of increase of annual rainfall towards north because of orographic effects. The low region along the course of River Ganga receives a rainfall of 1100 mm which gradually increases to 1500 mm in Champaran and 2100 mm in Purnea. The heavy rainfall, particularly in north Ganga Plain and in the higher catchments of Kosi and Gandak rivers in particular, causes floods. A region of rainfall (< 1000 mm) occurs in the south-central part of the state covering major areas of Nalanda and parts of Patna, Jehanabad, Nawada and Sheikhpura districts.

The aquifer system can broadly be divided into two categories (i) Fissured aquifer and (ii) Porous aquifer.

The fissured aquifers cover about 1/10th of the geographical area of the state in Rohtas, Gaya, Nalanda, Nawada, Munger, Jamui, Banka and Bhagalpur districts. Groundwater in this part occurs within the weathered zone (generally 10 to 25 m thick) and underlying secondary porosities like fractures, fissures and joints within 200 m bgl. The dug wells (8 to 12 m depth) tap low potential weathered zone. Exploratory drilling by CGWB has revealed occurrence of 2 - 5 sets of fractures underlying the weathered zone within 200 m depth. The cumulative discharge of the fractures generally remains within 5 lps. The thickness of individual fracture zone generally does not exceed 2 m. The groundwater occurs under unconfined condition within the fractured zone but long-duration pumping tests in exploratory wells of CGWB has revealed that in deeper fractured aquifer groundwater occurs under semi-confined condition at many places.

The vast Gangetic alluvial deposits covering the North and South Bihar Plains hold porous aquifer system. The drilling of CGWB dovetailing the geological information available from Geological Survey of India indicates that Quaternary deposits extends at least down to 300 m bgl in the northern part of South Ganga Plain and in major part of North Ganga Plain. In the southern part of South

Ganga Plain Quaternary deposits are lying unconformably over northerly sloping Precambrian basement which is exposed as Precambrian Highlands along the southern border of Bihar state. In South Bihar Plain aquifer comprises medium to very coarse grained and sometimes gravelly sands and thus rendering a high potentiality to the aquifers. Discharge in the northern part of the unit, bordering river Ganga varies from 150 to 250m3/hr which reduces to even less than 50m3/hr in the southern part in marginal alluvial plains. Transmissivity of this aquifer varies from 6000 to 12000 m2/day and generally reduces towards south because of dual effects of reducing hydraulic conductivity and diminishing aquifer thickness. In the marginal alluvial tracts the transmissivity is generally less than 500 m2/day. Groundwater in the productive aquifer system which is generally tapped by deep tube well, bore well and hand pumps lies under semi-confined to confined condition.

The north Bihar plain comprises two mega-fan Kosi and Gandak and vast stretches of fluvio-lacustrine deposits in between. Aquifers are comprised of medium to fine grained sand which becomes boulder towards north. At shallow level, within 50 m bgl, 1-3 zones are usually found having thickness of 3-10 m. The discharge generally ranges from 20-30 m3/day. Transmissivity of the shallow aquifer ranges from 400 to 700 m2/day and at deeper level 3-5 granular zones are encountered within 200 m bgl. The cumulative thickness ranges from 30-70 m. At places like Begusarai district the cumulative thickness of the granular zone increases considerably. In most of the wells tapping deeper aquifers, the discharge remains between 100 and 150 m3/hr. Maximum discharge is recorded as 208 m3/hr. Transmissivity ranges from 240 to beyond 6000 m2/day.

The Premonsoon water levels indicate that in major part of South Bihar Plain water level remains below 5 m bgl. Along the marginal alluvial plain bordering the Precambrian Highlands and piedmont surfaces water level goes deeper and remains below 7 m bgl. In the major part of the North Bihar Plain the level remains between 2 and 5 m bgl. During November the level remains between 2 and 5 m below ground, covering the major part of the state. In patches of South Bihar Plain the level remained between 5 to 10 m bgl.

The long term analyses of water levels do not reveal any lowering trend for any patches with significant aerial extent. However there is lack of time vs. water level data for deep aquifers. It has been reported that in major urban areas like Patna, Muzaffarpur, Ara, Gaya, Bhagalpur stress is being created on the deep aquifer system because of over withdrawal and witnessing lowering of water levels.

The state of Bihar is bestowed with substantial groundwater resources both static and replenishable. The replenishable resource represents ground water availability in the shallow aquifer between pre- and post-monsoon water level. In the state monsoon is the main source of ground water recharge. The latest assessment made as on March 31, 2004, on the basis of GEC 1997 considering community development blocks as assessment units (515 blocks). Total annual groundwater recharge has been worked out as 29.19 bcm. Considering the natural discharge during non-monsoon period Net Ground Water availability is 27.42 bcm. Existing groundwater draft for irrigation and domestic uses are 0.94 and 0.14 bcm respectively (total draft 1.08 BCM). The stage of groundwater development of the state as a whole is 39%, indicating thereby a vast scope exists for further ground water extraction. All of the 515 blocks assessed are falling under “safe” category where stage of groundwater development remains within 70%.

Below the zone of water level fluctuation (the resources which is reflected in the replenishable resource) a vast reserve of resource is available as static resources. A first approximation has been made for the in storage ground water reserve for each district separately for alluvial and the hard rock areas, for alluvial areas the resource has been worked out up to a depth of 450 m or the depth of the basement whichever is less, whereas, in hard rock areas the resource has been estimated for 100 m depth). In alluvial areas the in storage ground water reserve has been estimated as 2526 bcm, whereas in the hard rock areas it works out as 2.5 bcm

Ground water quality in the phreatic aquifer is generally good and can be safely used for drinking and irrigation uses. However , high concentration beyond the permissible limits of various chemical constituents has also been reported in different parts of the state, like high loads of arsenic, fluoride and iron from geogenic sources. Similarly , anthropogenic source like high nitrate has been reported in isolated pockets linked to high use of fertilizers.

High concentration of Arsenic (>0.50 mg/l) and Fluoride (>1.5 mg/l) in ground water is posing challenge to drinking water supply in the affected areas. Arsenic contamination is confined in the shallow aquifer system (<60 m bgl) in Holocene deposits along the course of the river Ganga. High spatial variability creates patchiness in distribution of arsenic contaminated wells. As per the latest information arsenic hotspots are distributed in 57 blocks covering 15 districts bordering River Ganga. Fluoride contamination is affecting the districts bordering the Precambrian Highlands in south. Fluoride contamination is distributed in 14 blocks of eight districts in South Bihar Plain and one block (Basantpur) in Supaul district of north Ganga Plain.

To provide assured supply for farm sector a scheme has been implemented named Million Shallow Tube Well Scheme. The intention of the scheme was to use part of the huge replenishable groundwater resource for agriculture. The 30% of the tube well and pump set cost (Rs.30 to 50 thousand) was subsidy from Govt. of Bihar, 20% was farmers' contribution and 50% as loan from the nationalized banks. The tube wells are 30 -70 m depth for the alluvial areas with a potential of 2 ha. Till date 0.4 million such shallow tube wells have been installed in the state. This scheme was sanctioned for 2001 to 2008 during 9th and 10th five year plan periods. The scheme has been replaced by a new scheme during 11th plan (2009-1012). The scheme has been named Bihar Ground Water Irrigation Scheme to harness the ground water resources.

7.1.2 Future Development Plan

The most important challenge for future irrigation in Bihar is its exploding population. By 2050, the population of the state is expected to cross 20 Crore. The decadal growth rate of rural and urban populations are 28.33% and 29.31% respectively. Considering per capita per day requirement of 40 liters for rural areas, the projected demand for the rural areas would be 3.782 BCM for the year 2051 against 1.083 BCM for the year 2001. There would thus be an increase of 249% in demand from the year 2001 level. For the urban areas the per capita per day requirement has been taken as 140 liters. The demand for urban areas would increase from 0.443 BCM (2001) to 1.560 BCM for the year 2051, an increase of 252% from the 2001 level.

The pressure of increasing magnitude of irrigated area in Bihar has to be mainly on groundwater. Due to reliability in water supply the yields in groundwater irrigated areas are higher. Therefore groundwater has to contribute maximum to increase substantially the irrigation intensity from 52% at present to 80%.

As on 31st March 2004, groundwater draft for irrigation was 9.39 BCM. A perusal of previous minor irrigation census data and interaction with state govt. officials indicate 1% annual increase in draft for irrigation. For the year 2009 the estimated draft for irrigation is 9.87 BCM. Keeping aside the allocation for drinking up to 2050, groundwater availability for uses other than drinking is 17.55 BCM. Considering the decadal growth of population in rural and urban areas as that of 1991-2001, total ground water draft for drinking use is 1.86 BCM for the year 2009 which would increase to 5.34 BCM in 2051. However, there is a strong possibility of increase of per capita consumption in view of betterment of life style. Keeping drinking as first priority and setting aside 5.342 BCM required for drinking in 2051, 12.21 BCM (17.55-5.34) can be diverted for enhancing the irrigation potential. This volume can provide assured irrigation to 22.42 lakh ha to enhance the irrigation intensity in Rabi and Khariff season in particular.

In storage ground water reserve in the deeper aquifers of the state is 2526 BCM out of which 99.1 BCM pertains in the alluvial deposits. A part of the static resource particularly in North Ganga plain can be allowed to develop by large diameter deep tube wells (200m depth). The hydrogeology of the area clearly indicates that in such a case there would be adequate transfer of water from shallow to the deep aquifer system where major part of the static resource is locked. The shallow water level in mid monsoon season in large part of North Ganga plain indicates that there is lot of rejected recharge during monsoon season and evapotranspiration loss. It is believed that if ground water development is given emphasis in North Ganga plain there would be a concomitant increase in the replenishable ground water resource. Thus the emphasis in North Ganga plain is enhanced ground water development.

The ephemeral rivers like Phalgu, Panchanan, Morhar, Quil etc should be harvested for making water available till the early pre-monsoon season. The recharge through the thick river bed sand deposit would help to build up the ground water resource. Water intensive industries like, sugar, agro-processing, packaged drinking water and mineral water can take the immense benefits of the copious availability of the good quality water available close to the land surface.

Enhancement of ground water extraction should not affect the water bodies that dot the north Bihar plain. Some of the water bodies are seasonal like Mokama tal in South Ganga plain. A scrupulous environmental auditing is warranted for the seasonal and perennial water bodies like cutoffs, ox-bow lakes and back swamps before any large scale increase of abstraction is contemplated for North Bihar plain.

The action plan for groundwater development in Bihar should also include

- Rehabilitation, maintenance and construction of public tube wells
- Renovation of dug wells in areas with geogenic contamination
- Artificial recharge schemes in marginal alluvium and piedmont areas of south Bihar Plains
- Groundwater abstractions using alternative (non-conventional) energy
- Estimation of evapotranspiration loss and component of rejected recharge in north Bihar plain
- Stage of groundwater development in Bihar is to be brought to 60% mainly in the North Bihar Plains,
- Groundwater ecology of water bodies in north Bihar plains
- Reclaiming water-logged areas by increasing groundwater abstractions in North Bihar Plain

7.2 Punjab

The State of Punjab covers an area of 50362 sq.km. The population of the State is 2,43,58,999 (2001 Census) which is constituting 2.37 % of the total population of the country. The economy of the state is primarily agro based.

There are six distinct physiographic zones and the State is drained by three major rivers namely Ravi, Beas and Sutlej. The State receives about 660mm normal rainfall out of which 80% occurs during southwest monsoon. July and August are the wettest months contributing about 57% of the annual rainfall. Three rivers feed a vast net work of canal system in the State and even provide water to Haryana, Rajasthan and J&K.

Punjab mainly occupies the Indo-Gangetic divide formed due to the tectonic uplift during the Pleistocene. In major part of the State, depth to water level ranges between 10 to 20mbgl. Water levels within 2.0 m occur in southwestern part in state in parts of Muktsar, Faridkot and Ferozpur districts. Shallow water levels, within 5m depth occur along flood plains of river Ravi, Satluj and Beas and in the south western part of the state. Depth to water level is more than 20 mbgl around major cities of the State viz. Amritsar, Jalandhar, Ludhiana, Moga and Sangrur. Water levels, deeper than 20m occur in Kandi areas in Hoshiarpur and Ropar districts. In the Plateau region of Garshankar block of Hoshiarpur district, it ranges between 50-180 mbgl. During the past 28 years (1975 - 2003) there is a decline in the fresh ground water areas of the State. Out of 50,362 Sq.km area of the State, 39,000 Sq.Km area (78%) exhibits a decline in water levels, covering major part of the State which includes most of Amritsar, Gurdaspur, Jalandhar, Ludhiana, Moga, Faridkot, Sangrur, Fatehgarh Sahib, Patiala, Faridkot, major part of Mansa and northern part of Ferozepur and Bathinda districts. The fall in water levels is between 4 to 16 meters. In southwestern part of the State, covering major parts of Muktsar, southern part of Ferozepur and southwestern part of Bathinda and Mansa districts and northeastern part of the State along Siwalik hills, a rise in water level has been observed.

During the past two decades, significant water table decline has been observed in most parts of Punjab. The main cause of ground water depletion is its over-exploitation to meet the increasing demand of various sectors including Agriculture, Industry and Domestic. Extensive paddy cultivation, especially during summer months has affected the available ground water resources adversely. Due to declining water table, the tube wells have to be deepened and the farmers are shifting to the use of submersible pumps in place of centrifugal pumps being used by them till now, resulting in additional expenditure and extra power consumption. This has adversely affected the socio-economic condition of the small farmers. This declining water table trend, if not checked, would assume an alarming situation in the near future affecting agricultural production and thus economy of the State and the Country. The most suitable artificial recharge methods adopted are by modifying the drain beds , abandoned river channels, village ponds,tanks and sarovar water. In a Kandi tract of the State low height dams across *choes* are constructed for water harvesting.

The drillings carried out in 'Kandi' and 'Beet' area has revealed that these waterless areas possess very promising water bearing zones at deeper levels. Water levels are deep seated, These areas are being developed as high technology is available to tap the ground water resources , occurring at deeper levels. The studies have shown that these areas are ground water worthy, the green revolution has started and extending to these dry areas.

Irrigation by groundwater in the State is mainly through tube wells both shallow and deep. The shallow tube wells in the depth range of, up to 50m are owned by farmers, whereas, deep tube wells are constructed by the State Government for direct irrigation and drinking purposes. In the following 12 districts, groundwater irrigation accounts for more than 50% of the total irrigation-Hoshiarpur 82%, Gurdaspur 78.55%, Amritsar 64.55%, Kapurthala 89.4%, Jalandhar 83.5%, Patiala 94%, Fatehgarh Sahib 93.55%, Sangrur 67.31%, Ludhiana 95.6%, Ferozepur55.7%, Nawanshahar 93% and Ropar 54%.

7.2.1 Management Measures :

Owing to steep slopes of the hills in Kandi belt falling in Hoshiarpur and Ropar districts flash floods are common in these areas and with the result there is a soil erosion in the area. With the construction of low height dams, damage of soil erosion and crops can be controlled. The depth to water in the area is deep due to which the conventional irrigation facilities like tube wells are either beyond reach of the common farmers or not feasible, and thus rendered this area backward. Micro level studies need to be taken up in the blocks which fall under over exploited category. The draft figures should be verified in the field by installing hours meters. Wherever draft has been taken on higher side, corrections may be made and recasting of water balance be carried out .Studies on Conjunctive Use of ground water and surface water resources be taken up in south western part of the State where ground water is highly mineralized and water logging has become menace.

The farmers have adopted paddy cultivation due to profitability and incentives from the Government leading to extensive development of ground water in the northern parts of the State. There is an urgent need to change the cropping pattern in these areas and to adopt cultivation of those crops which require less irrigation.

In southwestern parts of the State covering parts of Ferozepur, Faridkot, Muktsar, Bathinda and Mansa districts, the water table is rising due to limited/non-extraction of ground water because of its brackish / saline quality and thus being unfit for drinking, domestic, irrigation and other purposes .

Flood plains of Ravi, Beas and Satluj rivers are underlain by potential sub-surface reservoirs down to explored 400m depth. It is considered feasible to dewater and refill shallow aquifers on sustainable basis. This resource, which has remained unexploited could provide enormous amount of fresh ground water on sustainable basis. High capacity tube wells of about 2 cusecs (200 m^3/hr) capacity can be installed in these areas, as the underlying sandy formations are highly potential.lt would also help to reduce evaporation losses and water flowing to Pakistan during Monsoon period.

In city areas, stress on pumping of ground water is increasing to meet the ever-increasing demand of water for domestic and industrial uses. This has resulted decline of water levels at faster rates as compared to adjoining rural areas. It has been observed that in the most major cities of the State, the water levels are falling at a rate of 0.50m to 0.60m per year. This over exploitation of ground water has caused formation of ground water troughs in the central part of the cities resulting in increased energy consumption. In order to arrest the water table decline, either canal water should be supplied to the thickly populated areas or well fields may be developed in the outskirts of the cities and water be supplied through pipeline

In the flat topped hilly areas and low hills of Siwalik, sandstones constitute good water bearing zones. These areas comprises of 'Beet area' of Garhshankar block, low hills of Dasua, Bhuga and Talwara blocks of Hoshiarpur districts. These areas require special attention to mitigate the water needs of the people. The areas have been explored by the Central Ground Water Board and proved ground water worthy.

7.3 West Bengal

The State of West Bengal is principally an agrarian state with more than 70% of its population depend directly or indirectly on agriculture for their livelihoods. Irrigation projects account for 47.70% of the gross cropped areas of 9778815 ha (with cropping intensity 177%). Irrigation in the state is being effected through major, medium and minor irrigation programmes. About 75% of the irrigation is being done through minor irrigation schemes.

The development of agrarian economy needs expansion of irrigation facilities. The state is having huge groundwater reserve and at present the stage of groundwater development is only 42 percent of the available resources. Though huge reserve of groundwater resource is available, every drop of ground water needs proper management. Keeping the above facts in view an attempt has been made to depict the hydrogeological framework by synthesizing all the available data related to hydrogeological condition with a view to assess the ground water development prospect of the state. The Himalayan ranges from the northern boundary of the state while Bay of Bengal forms the southern boundary. Normal annual rainfall in the State ranges from 1234 mm to 4136 mm. Himalayan region receives the maximum rainfall.

The State is divided into three distinct physiographic units as

(i) Extra – Peninsular Region of the north, comprising mainly Himalayan Foot Hills, falling in Darjeeling, Jalpaiguri and Kochbehar districts

(ii) Peninsular mass of the south – west forming a Fringe of Western Plateau, covering the entire district of Purulia, western part of the districts of Barddhaman, Paschim Medinipur and Birbhum and the northern part of Bankura district
iii) Alluvial and Deltaic plains of the south and east.

a) Deltaic zone falling in Sundarban area of the district of South 24 Parganas and in a small part of North 24 Parganas district and
b) Plain flat terrain falling in the remaining areas of the state.

There are three major river basins in the state namely- the Ganga, the Brahmaputra and the Subarnarekha. In the northern part of the state Teesta is the main river which along with Torsa, Jaldhaka, etc. are the tributaries of the Brahmaputra river. Mahananda is the main river meeting the Ganga in the north of the state. The state of West Bengal is covered by diverse rock types ranging from the Archaean metamorphites to the Quaternary unconsolidated sediments. Approximately two -third area of the State is covered by alluvial and deltaic deposits of Sub – Recent to Recent time and the remaining part abounds in a wide variety of hard rocks.

The entire West Bengal state can be grouped under two broad hydrogeological units, e.g.

- Porous hydrogeoological unit
- Fissured hydrogeological unit

Nearly two-third of the state is occupied by a thick pile of unconsolidated sediments laid down by the Ganga-Brahmaputra river system, the thickness of which increases from marginal platform area in the west towards the east and southeast in the central and southern part of the basin following the configuration of Bengal Basin. These unconsolidated sediments are made up of succession of clay, silt, sand and gravel of Quaternary age overlying Mio-Pliocene sediments. The Quaternary sediments are made up of recent and older alluvium. Occurrence and movement of ground water in this hydrogeological unit is controlled by the primary porosities of the sediments.

A thick profile of in situ soft porous material develops as a disintegration product on the upper most part of the hard, consolidated rock due to weathering. Weathering imparts secondary porosity to the hard rock which either has been compact or fractured at different places under different set of conditions. Weathered mantle derived from upper part of parental hard rock, varying in thickness from <1 m to 5 m in extra-peninsular region and from 5 to 15 m in peninsular region forms the depository of ground water as shallow aquifers in the area occupied by the hard rocks. Ground water in these depositories occur under unconfined condition, and in general developed by medium to large diameter open wells, the depth of which varies according to the thickness of the weathered rock available. In the Himalayan hilly terrain groundwater development by open wells tapping the weathered residuum, cannot be done as groundwater moves away from the higher elevation to lower elevation very fast, resulting in the open well getting dry soon.

7.3.1 Ground Water Resources in West Bengal

The latest assessment made as on March 31, 2004, on the basis of GEC 1997 considering community development blocks as assessment units . Total annual groundwater recharge has been worked out as 30.36 bcm. Considering the natural discharge during non-monsoon period Net Ground Water availability is 27.46 bcm. Existing groundwater draft for irrigation and domestic uses are 10.84 and 0.81 bcm respectively (total draft 11.65 BCM). The stage of groundwater development of the state as a whole is 42%, indicating thereby a vast scope exists for further ground water extraction. All of the 515 blocks assessed are falling under “safe” category where stage of groundwater development remains within 70%.

Based on stage of ground water development and long term pre and post monsoon water level trend , out of 269, there are 37 blocks have been categorized as Semi-critical and 1 no. of blocks as Critical . The rest of the blocks are under ‘**Safe**’ category.

7.3.2 Issues Related to Ground Water Development

The various issues emerged during Ground Water Development in West Bengal are:

- Chronically water scarce area in western part and in hilly tract in the northern part of the State.
- The area where depletion in water level has been ascertained.
- Hazards due to mining activity in Coal mine area and
- Area falling under Geogenic contamination: High arsenic, High fluoride, High salinity and High iron

7.3.2.1 Chronically water scarce area in western part and in hilly tract in the northern part of the State:

The districts of Purulia, western part of Bankura, Birbhum, Barddhaman, Paschim Medinipur face acute scarcity of water, mainly during the lean period due to limited yield potential of available aquifers. However, CGWB has identified potential deep fractures and successful bore wells have been handed over to State agency to augment their water supply system.

7.3.2.2 Area where depletion in water level has been ascertained:

- In KMC area, the piezometric surface in the Central Kolkata has been lowered to the tune of 5-9 m in the last 40 years forming a huge ground water trough due to withdrawal of ground water in excess of replenishment. Depth to piezometric level in the area varies from 3.34m to 16.32 m bgl in pre monsoon period and from 1.57m to 15.71m bgl in post monsoon period. Long term analysis of piezometric level data also shows a distinct falling trend of piezometric level in both pre and post monsoon period. A recent project of artificial recharge to deeper confined aquifer using roof top rainwater in KMC area (Baishnab-Ghata Patuli) has been proved to be very successful.

- The Haldia Industrial Complex area falls in the coastal plains of West Bengal and fresh aquifers occur in the depth span of 120-300 mbgl. The piezometric level of the fresh ground water in the area lies within 7-15 m bgl. Study indicates that there is a distinct lowering of piezometric level of the fresh ground water to the tune of 5-7 m during last three decades due to heavy withdrawal of ground water from large no of heavy duty tube wells constructed by several organizations. As a result of this heavy withdrawal of fresh ground water, a ground water trough has been formed in the area close to the river Hugli. In order to avoid probability of sea water ingress into the aquifers, the same aquifers have been notified under CGWA to restrict withdrawal of ground water from the aquifers.

7.3.2.3 Area falling under Geogenic contamination:

- **High arsenic in ground water:**

Arsenic contamination in ground water occurs in isolated patches in spreading over 79 blocks in eight districts namely, Malda, Murshidabad, Nadia, North 24 Paraganas, South 24- Paraganas to the east and Haora, Hoogly and Bardhaman to the west of Bhagirathi/ Hoogly river. Eastern part of Bhagirathi/ Hoogly river is much more affected than the western part. Deeper aquifers (> 100 mbgl) in the same area are generally free from arsenic. Ground water in arsenic affected area is characterized by high iron, calcium, magnesium, bicarbonate with low chloride, sulphate and fluoride.

- **High fluoride in ground water**

The Task Force on Fluoride Contamination had recommended rapid assessment of fluoride concentration in ground water in 105 blocks of 12 districts of West Bengal. After the assessment, the final scenario regarding the high fluoride concentration in ground water of West Bengal has been observed in 43 blocks of 7 districts, namely Bankura, Birbhum, Purulia, Malda, Uttar Dinajpur, Dakshin Dinajpur and South 24 Parganas. However this problem is most serious in Bankura, Birbhum, Purulia and Dakshin Dinajpur districts. CGWB has found fluoride contamination above the permissible limit in Nadia and Bardhaman district as well. In the state highest concentration of fluoride in groundwater has been reported from Khyarasol block (15.9mg/lit) and Rampurhat-I block (17.9mg/lit) of Birbhum district.

- **High salinity**

Based on the geophysical surveys and ground water exploration, Brackish to saline and fresh water bearing aquifers have been deciphered in the different depth zones in Kolkata Municipal Corporation area, South 24 Parganas and in parts of North 24 Parganas, Haora and Purba Medinipur districts.

- **High iron in ground water**

Iron content in some isolated patches of Medinipur, Haora, Hugli and Bankura iron content is somewhat higher than 1 ppm and sometimes it exists more than 2 ppm in Haora and parts of Hugli districts. Likewise, in the Himalayan foothills in the districts of Darjeeling and Jalpaiguri ground water in near surface aquifers have iron as high as more than 3 ppm at places.

8. Conclusions:

The highly diversified hydrogeologic settings and variations in the availability of ground water resources from one part of the country to other call for a holistic approach in evolving suitable management strategies. The emphasis on management needs does not imply that ground water resources in India are fully developed. Effective management of available ground water resources requires an integrated approach, combining both supply side and demand side measures.

There is a vast area in the Indo Gangetic alluvial plain where the ground water development is sub optimal and there is sufficient scope for future development. Similarly, urgent action is required to augment the ground water in the water stressed areas. However, focus on development activities must now be balanced by management mechanisms to achieve a sustainable utilization of ground water resources. Ground water constitutes the most important source of irrigation water in the Gangetic plains including the three states i.e. Bihar, Punjab and West Bengal. The productivity in terms of agricultural output is relatively low in Bihar and West Bengal as compared Punjab. Though, groundwater development for irrigation is feasible in these areas based on hydrogeological and environmental considerations , there is often a great economic barrier for the predominantly small and marginal farmers . A multitude of mechanisms have been developed or have emerged in these areas to enable farmers to benefit from ground water. Assured power supply is one of the key factors, the tariff, access and availability of which to a large extent determines the ground water use. Since the ground water development is mostly demand driven, it can be geared up through proper agricultural, credits, subsidy and energy support policies along with creation of suitable markets. In addition, the flood plains along the major river courses of the country offer good scope for groundwater development. Similarly, there are areas in the country with artesian condition, which can be mapped and suitable development plans formulated. In the alluvial areas, where multi-aquifer systems exist, there is a need to concretize methodologies for assessment of development potential of deeper aquifers. There is urgent an need for coordinated efforts from various Central and State Government agencies, non-Governmental and social service organizations, academic institutions and the stakeholders for evolving and implementing suitable ground water management strategies in the country.

References

- Jha B.M.. (2007) , Management of Ground water resources for Ensuring Food Security in India, National Ground Water Congress, New Delhi
- Central Ground Water Board (2002), Master Plan for Artificial Recharge to Groundwater in India. New Delhi.
- Central Ground Water Board (2006), Dynamic Ground Water Resources of India . New Delhi.
- Das, S. (2006), Groundwater overexploitation and importance of water management in India – Vision 2025. Tenth IGC foundation lecture. The Indian Geological Congress, Roorkee.
- Llamas, M. Ramon, Mukherjee, Aditi and Shah, Tushaar (2006), Guest editors' preface on the theme issue "Social and economic aspects of groundwater governance. Hydrogeology Journal, vol. 14(3), pp. 269-274.
- Ministry of Water Resources (2002), National Water Policy. New Delhi.
- Minor Irrigation Division (1993), Report on Census of Minor Irrigation Schemes – 1986-87. Ministry of Water Resources, New Delhi.
- Minor Irrigation Division (2001), Report on Census of Minor Irrigation Schemes – 1993-94. Ministry of Water Resources, New Delhi.
- Minor Irrigation Division (2005), Report on 3rd Census of Minor Irrigation Schemes – 2000-01. Ministry of Water Resources, New Delhi.

- National Institute of Hydrology, Roorkee and Central Ground Water Board (2006), An operational model for groundwater pumping at Palla Well Fields, NCT Delhi – Project Report.
- Planning Commission (under publication), Ground water ownership in the country. Draft report of the Expert Group.
- Romani, Saleem (2006), Groundwater Management – Emerging challenges. Groundwater Governance – Ownership of Groundwater and its Pricing. Proceedings of the 12th National Symposium on Hydrology. November 14-15, 2006. New Delhi.
- Shah, Tushaar and Shilp Verma (2007), Real-time Co-management of Electricity and Groundwater: An assessment of Gujarat's Pioneering Jyotigram Scheme - Discussion paper. International Water Management Institute (IWMI).
- Ground water governance in the Indo-Gangetic and yellow River Basins - Realities and Challenges. Edited Vol. Aditi Mukherjee et.al, IAH selected papers.