Groundwater Governance: Few Pertinent Issues Relating to Availability and Possible Threat

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Abstract: The governance issue emerges when there is disproportion in supply and demand, conflicts in sharing and interest of users, disparity in priorities of allocation, threat to availability due to interfering polluting matter, etc. The supply or the availability of groundwater in a specific location or in an area normally remains unaltered due to the fact that parameters such as rainfall in a year and hydro-geological features that retain water in the subsurface remain unchanged. Thus, management of demand and readjustments of supply both spatially and temporally could form the primary focus in groundwater governance; other issues automatically subside when demands are met adequately. However, the supply and demand management of ground water is governed by a number of constraints, such as, hydrological and hydro-geological variability, population growth and their water requirement, land uses, pollution hazards, etc. Considering hydrologic, hydro-geologic, and demographic homogeneity on a regional scale with river basin and administrative boundary as the scale unit, the availability of replenishable groundwater resources in terms of depth per unit area and the change in per capita availability over the next two decades has been assessed. The analyzed results are indicative only because of the assumptions involved. Projections have been made regarding the statewise additional per capita groundwater requirement in the coming years. The scope for augmentation of groundwater resources to meet the additional requirement and the probable threat to aquifers due to pollution hazards is also discussed.

INTRODUCTION

Governance can be defined as the act of an empowered management body expected to function in broader interests. According to the United Nations Development Program (UNDP) *governance is the exercise of political, economic and administrative authority in the management of a country's affairs at all levels. It is a neutral concept comprising the complex mechanisms, processes, relationships and institutions through which citizens and groups articulate their interests, exercise their rights and obligations and mediate their differences* (UNDP, 2006). Water governance is a component of "Governance" that describes political, economic, administrative, and social processes as well as institutions by which public authorities, communities and the private sector take decisions on how best to develop and manage water resources. Groundwater governance is a part of the water governance that deals with issues and developments related to groundwater.

India is an enormous country having its own political ideologies, diverse religious spirit, multiple languages, varying climate and topography with differing land and water uses, developing economy with substantial economic gap between urban and rural sectors, and a booming population. The cumulative effect of these factors coupled with lack of adequate literacy has given rise to many unforeseen threats to the natural resources of the country. Ground water is one such resource that gets replenished annually. A groundwater aquifer has some unique features, such as; slow flow rates and long residence times, which result in retention of large volumes of water in the subsurface. These features along with other merits such as easy availability of ground water at point of demand have led to its indiscriminate withdrawals giving rise to scarcity of ground water in many areas.

India is fortunate to have a consistent hydrologic cycle with about four months monsoon duration (June through September) besides having hydrogeologically favourable features such as alluvial formations and fractured crystalline rocks and basalts that can hold sufficient reserves of water. However, the major concerns are: neither the distribution of groundwater availability is uniform, nor the usages (or demands) of ground water are in proportion to the availability.

Ground water is used in domestic, agricultural, and industrial sectors, and its demand in all these sectors is on a continuous rise. The need to accomplish food security for the expanding population, rapid industrial growth, health consciousness and desire for higher standards of living are a few of the major issues behind the increasing demands. Over-exploitation of ground water and improper disposal of waste matters, on the other hand, are posing a threat to the availability of ground water. The necessity is to develop appropriate groundwater management strategies for each hydrogeologic basin based on water uses and demand pattern both for long- and short-term as well as for regional and local scale, keeping spatial and temporal variability of groundwater availability as the guiding factor.

The paper analyses the status of groundwater availability including its future trend of availability both river basin-wise and in terms of per capita availability. Few key issues related to the changing scenario of availability and the likely threats to availability of ground water including the scope for augmentation of resource to meet the future requirement have also been discussed.

GROUNDWATER INPUT-OUTPUT COMPONENTS

In a groundwater system, inputs to its storage comprise: (a) recharge from rainfall, (b) recharge from field irrigation, canal and tank seepage, and (c) inflows from river and other adjacent basins. Outputs from storage comprise: (a) evaporation and evapotranspiration, (b) draft from ground water, and (c) outflows to river and other basins, etc. Inputs lead to gain in storage but outputs result in loss from storage. Difference of inputs and outputs is the accumulated storage over a specific period of time. In fact, rainfall recharge is the only input component that contributes to the ground water as replenishable resource from external source. All other inputs are indirect components having moved from other surface or groundwater storage. Therefore, rainfall recharge and loss of water through evaporation during surface storage for groundwater recharge operations are the two components, which govern the availability of ground water (replenished) in terms of depth per unit area. Controlling these two components i.e., maximization of rainfall recharge and minimization of evaporation, would in turn lead to an increase in storage volume. This paper analyses availability of ground water considering the estimated potential of groundwater resources as the net volume of replenishable groundwater resources available in a year.

HYDROGEOLOGICAL SETUP OF INDIA

India has varied hydrogeological formations ranging in age from Archaean to Recent; physiographically, these are known by rugged mountainous terrains of Himalayas, Eastern and Western Ghats, Deccan Plateau, flat alluvial plains of river valleys, coastal tracts, and aeolian desert in western parts (CGWB, 1995). The various geological formations and their areal extents are shown in Fig. 1 with some additional details given in Table 1. These geological formations act as repositories of ground water in respective areas and also give shape to the spatial and temporal variation of infiltrated rainwater.

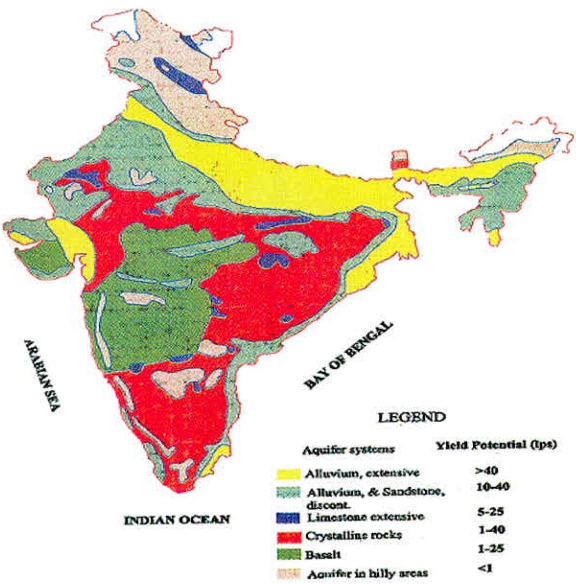


Fig. 1. Major aquifer systems in India (after CGWB, 2002).

Rainfall and Availability of Water

Although normal monsoon season is of four months duration (June through September), however, intensity, duration, and interval between two successive events of rainfall vary geographically according to the hydrological variability. The rainfall varies from a minimum of 100 mm in western-most regions to a maximum of 11,000 mm in eastern-most regions. The average of annual rainfall of 129 years (1871-1999) is found to be 1079 mm with maximum of 1170 mm during 1990-1999, and minimum of 903 mm during 1881-1890. Analysis of average annual rainfall data (IMD, 2003) of ten years (1990–1999) shows that out of 28 States and seven Union Territories, Rajasthan had minimum annual rainfall of 566 mm among the States, and Daman & Diu had minimum annual rainfall of 497 mm among the Union Territories, whereas maximum annual rainfall of 3329 mm and 2548 mm were respectively observed in Kerala among the States and Andaman & Nicobor among the Union Territories. Nearly 75% of the annual rainfall normally occurs during monsoon months.

Out of the total geographical area of 32,87,263 km^2 of India, about 97% is covered by major river basins (MOIP, 1972). Statewise sharing of catchments of the major river basins (compiled from published literature) is given in Table 2. The average annual rainfall (1990-1999) of these river basins

Taeble 1. Hydrogeological set up of India (CGWB, 2002)

Groundwater provinces	*Formations*	*Hydro geological characteristics and aquifer properties*	*% extent in terms of total geographical area (Source: compilation of information)*
Himalayan highland province	• Fluvio-glacial deposits, Glacio-lacustrine deposits. • Himalayan foot hill deposits.	• Morainic deposit. Lacustrine deposits containing cyclic layer of clayey, silty and coarser deposits. Locally significant hydrogeological potential. • Belt containing productive boulder, cobble, gravel, and sand aquifers. The water table is deep. The deeper confined aquifers display flowing artesian conditions.	12.50
Ganges-Bhamaputra alluvium province	Alluvium with beds of sand, silt and clay with occasional beds of gravel, max thickness more than 2000 m (sub-recent to recent).	Shallow unconfined aquifers, deeper ones confined or leaky type. (T=1000–5000 m^2/day; S=10^{-4}–10^{-3}; Yield potential = 0.04– 0.11m ^{3}/s)	15.27
Alluvium and sandstone discont., and Precambrian sedimentaries.	• Unconsolidated to semi-consolidated sandstone, shales and limestones. • Consolidated sandstones, shales and limestone (Proterozoic)	• Deeper aquifer under confined condition; at places flowing wells. (T=500-5000 m^2/day; S=10^{-5}–10^{-3}; Yield potential =0.01-0.04m ^{3}/s) • Intergranular porosity low; fractures are the main source of water in sandstone and shales; solution cavities in limestones. (T=5-500 m^2/day; S = 10^{-3}-10^{-2}; Yield potential = 0.01-0.04m ^{3}/s)	14.25
Precambrian crystalline province	Crystalline rocks, viz. granites, gneisses and schists	Weathered mantle (regolith) is the main source of water supply; fractures and lineaments also facilitate groundwater movement. (T = 5-50 m^2/day; S = 10^{-1}- 10^{-2} Yield potential = 0.001-0.005m ^{3}/s)	44.45
Deccan trap province (Basalt)	Basalts, Dolerites, Diorites and other acidic derivatives of Basaltic magma.	Main source of groundwater are: (a) weathered and fractured horizon, (b) inter flow spaces, (c) inter-trappeans, (d) vesicular horizons. (T = 10-700 m^2/day; S=10^{-3}-10^{-1} and Yield potential = 0.001-0.03 m^3/s)	12.13
Gondwana sedimentary province	Semi-consolidated sandstones and shales with coal seams (carboni-ferrous to lower cretaceous)	Shallow aquifers unconfined, deeper ones confined. (T=50-500 m^2/day; S= 10^{-3}-10^{-1} and Yield potential = 0.01-0.04 m^3/s)	1.40

Table 2. Basinwise distribution of rainfall

River basin	*Catchment area (km^2)*	*Average annual rainfall (1990-1999) (mm)*	*Equivalent height of utilizable (UTL) and unutilizable (UUT) surface water runoff (mm)*	*Equivalent depth of annual replenishable groundwater (mm)*	*Covering states*	*Distribution of catchment area (km^2)*
Indus	3,21,289	1002.6	UTL: 85 UUT: 143	82	Himachal Pradesh	51,356
					Jammu &Kashmir	1,93,762
					Punjab	50,362
					Haryana	9,939
					Chandigarh	114
					Rajasthan	15,756
Ganga	8,61,452	1018.0	UTL: 290 UUT: 319	199	Uttar Pradesh	2,38,566
					Uttaranchal	55,845
					Himachal Pradesh	4,317
					Haryana	34,273
					Delhi	1,483
					Madhya Pradesh	1,93,358
					Rajasthan	1,02,883
					Bihar	94,163
					Chattisgarh	16,392
					Jharkhand	63,322
					West Bengal	56,850
Brahmaputra	1,94,413	2545.0	UTL: 101.7 UUT: 2378	228	West Bengal	12,585
					Sikkim	7,096
					Meghalaya	20,816
					Arunachal Pradesh	81,424
					Assam	61,485
					Nagaland	11,007
Barrack and others	41,723	2022.0			**Meghalaya**	2,243
					Tripura	10,453
					Mizoram	8,973
					Assam	10,000

(*Contd.*)

Table 2 (*Contd.*)

River Basin	*Catchment area (km^2)*	*Average annual rainfall (1990-1999) (mm)*	*Equivalent height of utilizable (UTL) and unutilizable (UUT) surface water runoff (mm)*	*Equivalent depth of annual replenishable groundwater (mm)*	*Covering states*	*Distribution of catchment area (km^2)*
					Manipur	4,369
					Nagaland	5,685
Godavari	3,12,812	1062.75	UTL: 244	130	Maharastra	1,52,000
			UUT: 109		Madhya Pradesh	65,265
					Orrisa	17,752
					Andhra Pradesh	73,365
					Karnataka	4,430
Krishna	2,58,948	1171.0	UTL: 224	102	Maharastra	69,347
			UUT: 77.7		Andhra Pradesh	76,252
					Karnataka	1,13,271
Cauvery	81,155	1146.0	UTL : 234	153	Karnataka	34,273
			UUT: 29		Kerala	2,866
					Tamil Nadu	43,867
					Pondicherry	149
Subarnarekha	29,196	1483.9	UTL :233	62	Jharkhand	13,685
			UUT : 190		West Bengal	11,964
					Orissa	3,547
Brahmani & Baitarani	51,822	1426.6	UTL : 353	78	Madhya Pradesh	1,316
			UUT:196		Jharkhand	15,757
					Orissa	34,749
Mahanadhi	1,41,589	1358.6	UTL : 353	102	Maharastra	238
			UUT:119		Chattisgarh	75,136
					Jharkhand	635
					Orissa	65,580
Pennar	55,213	1016.6	UTL: 124	89	Karnataka	6,937
			UUT: 0		Andhra Pradesh	48,276

(*Contd.*)

Table 2 (*Contd.*)

Mahi	34,842	671.6	UTL: 52.8 UUT: 26	49	Madhya Pradesh Rajasthan Gujarat	6,695 16,453 11,694
Sabarmati	21,674				Rajasthan Gujarat	4,124 17,550
Narmada	98,796	1001.6	UTL: 359 UUT: 102	110	Madhya Pradesh Maharastra Gujarat	85,946 1,538 11,400
Tapi	65,415	1041.0	UTL: 222 UUT: 5.9	127	Madhya Pradesh Gujarat Maharastra	9,804 3,837 51,504
West Flowing River from Tapi to Tadri	55,940	1889.5	UTL: 322 UUT: 1469	158	Maharastra Karnataka Goa Gujarat Dadara & Nagar Havbali	32,573 9,453 3,702 9,666 546
West flowing river from Tadri to Kanyakumari	56,177				Karnataka Kerala Tamil Naidu	15,550 35,925 4,702
East flowing river between Mahanadhi and Pennar	86,643	965	UTL: 159 UUT: 50	98	Orrisa Andhra Pradesh Tamil Nadu	25,740 40,383 20,520
East flowing river from Pennar to Kanyakumari	1,00,139				Karnataka Tamil Nadu Pondicherry	6,256 93,404 479
West flowing river of Kutch and Saurashtra	3,21,851	659.2	UTL: 52.8 UUT: 26	34.6	Rajasthan Gujarat Diu	1,93,392 1,28,420 39
Total	31,91,089					

estimated based on weighted average of areas shared by the respective State multiplied by the average annual rainfall of the shared States, is also given in Table 2.

Estimates given by the different investigators (CWC, 2005; CGWB, 1996) indicate that out of the total annual precipitation of about 4000 km^3 in India, the part that flows as natural runoff is about 1869 km^3, the part that joins the groundwater table (replenishable groundwater) is about 432 km^3, the part that evaporates immediately is about 700 km^3, and the remaining part retained in the soil as soil moisture or on the soil surface is about 1000 km^3 (these values are indicative only). Of the 1869 km^3 potential of surface water, only 48% (690 km^3) is utilizable. The Central Water Commission (CWC) and the Central Ground Water Board (CGWB) have given river basinwise estimate of average annual potential of both surface water and replenishable groundwater resources.

Table 2 gives the basinwise distribution of average annual rainfall and the catchment area of different states comprising a given basin. The table also provides equivalent height of utilizable and unutilizable surface water runoff along with equivalent depth of annual replenishable ground water. The analysis is based upon the assumption that surface water and replenishable groundwater potentials are uniform over a given basin and are derived from average annual rainfall. In terms of average annual rainfall of 1170 mm in the country, about 29.5% goes away as loss without creating scope for utilization, and about 11.5% is available in the form of replenishable groundwater resources. All the basins of west flowing rivers (except that of the Narmada and west flowing rivers of Kutch and Saurashtra), and the basins of rivers joining the Bay of Bengal, namely; Brahmaputra, Subernarekha, Mahanadi, Brahmani and Baitarani, Godavari, Krishna, and Cauvery lose maximum fraction of rainfall, varying between 60% and 81%, without contribution to surface water and groundwater storage.

POPULATION AND PER CAPITA GROUNDWATER AVAILABILITY

The 2001 census of India giving State wise and Union Territory (UT) wise population count gave an estimate of a total population touching 1027 million. The decadal rise of population from the year 1951 to the year 2001, including its average percent annual growth is shown in Table 3.

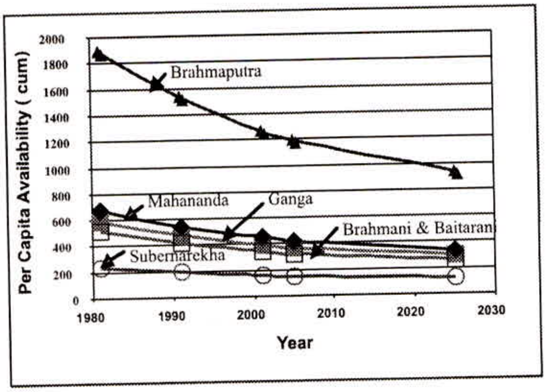
Table 3. Trend of population growth of India

Census Years	*Population (in million)*	*Average annual growth (per cent)*
1951	361.09	1.25
1961	439.23	1.96
1971	548.16	2.20
1981	683.39	2.22
1991	846.39	2.14
2001	1027.02	1.93
2005*	1089.64*	1.52*
2025*	1394.8*	1.40*

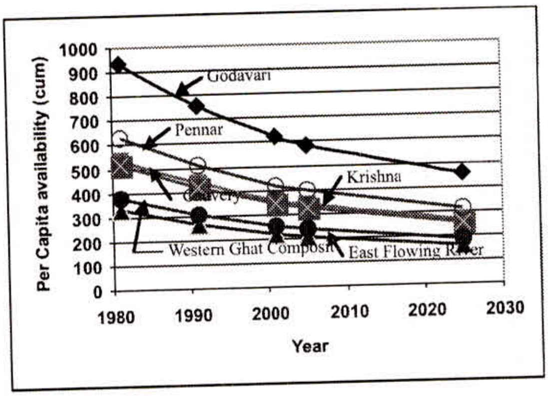
(*): Projected figure.
(*Source:* Census, 2001)

Making use of the trend of population growth (1995-2001) and the projected stabilizing population figure of 1640 million by the year 2050 as predicted by UN agencies, the expected population figures for the years 2005 and 2025 have been assessed and shown in Table 3. Considering the trend to be the same as per the average annual growth of the country, the population for each State and UT has been projected for the years 2005 and 2015. From the Statewise population projection, river basinwise population density (number of people per sq km) has been ascertained. Using the estimated population density, river basinwise change of per capita groundwater availability allocation since year 1981 has been computed. Assumptions made in the computations are: (i) in a river basin, rainfall and availability of ground water are uniform, and (ii) allocation of per capita availability accounts for groundwater requirement for other direct and indirect uses, such as, irrigation, industries, eco-system balance, etc.

River basin boundary and hydrogeological boundary can rarely be found to be the same; on the other hand, geological formations of groundwater repositories throughout a river basin can rarely be of the same hydrogeological setup. Based on hydrological, geographical and political commonality, the scenario of per capita allocation of average annual replenishable ground water since 1981 through 2025 has been analysed for the following three groups of river basins; (a) Eastern river basins, (ii) Southern river basins, and (c) Western river basins, and shown in Figs. 2 (a, b & c).



(a)



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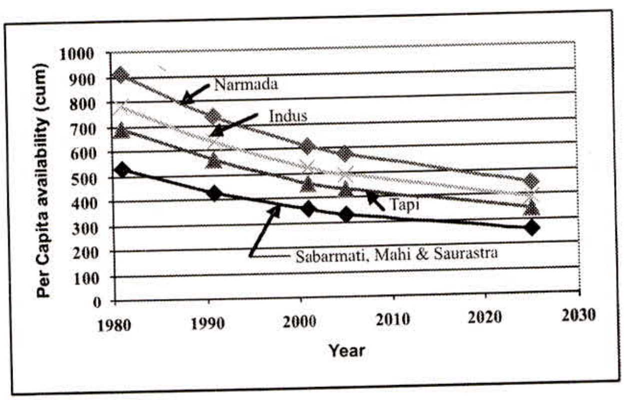

(c)

Fig. 2. Change of per capita allocation of average annual replenishable groundwater resource in different river basins in India, (a) Eastern river basins, (b) Southern river basins, and (c) Western river basins.

Although these figures are self explanatory, it can be seen that as time progressed, population in each river basin increased resulting in reduction of per capita availability of annual replenishable groundwater resources. Among all river basins, the Brahmaputra shows the highest per capita allocation all through from the year 1981 with a value of about 1850 m^3/year to a likely value of about 900 m^3/year in year 2025, while the Subernarekha has the lowest with about 225 m^3/year in year 1981 to a likely value that falls below 175 m^3/year. Except the Brahmaputra, the Godavari, the Narmada, and the Indus river basins, per capita availability of replenishable groundwater resources in all other river basins is likely to reduce with values ranging from 175 m^3/year to 400 m^3/year by the year 2025 against the per capita availability ranging from 225 m^3/year to 675 m^3/year in the year 1981. CWC (2000) has projected that by the year 2025, the average annual water requirement for the whole country in different sectors of uses may touch a figure of 1092 BCM against a much lower requirement of 634 BCM in the year 2000. The distribution of 1092 BCM amongst different sectors can be given as: (a) domestic 73 BCM (per capita requirement 52.34 m^3/year), (b) irrigation 910 BCM (per capita requirement 652.4 m^3/year), (c) industry 22 BCM (per capita requirement 15.77 m^3/year), (d) energy 15 BCM (per capita requirement 10.75 m^3/year), and (e) others 72 BCM (per capita requirement 51.6 m^3/year). These values add up to a total per capita requirement of 782.86 m^3/year by the year 2025 for the projected population of 1394.8 million. The proportions of utilizable groundwater and the utilizable surface water to the total utilizable water resources (1122 BCM) are about 38.5% and 61.5%, respectively (IWRS, 1999). Considering that these percentage shares of surface and groundwater remain valid in per capita water requirement as well, the average annual per capita groundwater requirement by year 2025 is worked out to be 391.7 m^3/year. The river basins, which may fall short of meeting the above projected requirement by the year 2025, could be (Figs. 2 a, b and c): (i) Brahmani and Baitarani, and Subernarekha among the Eastern river basins, (ii) Krishna, Cauvery, Western Ghat composite (comprising east and west flowing rivers), and east flowing rivers among the Southern river basins, and (iii) Sabarmati, Mahi and the Saurashtra region among the Western river basins.

Statewise potential of annual replenishable groundwater resources has been assessed in terms of depth over per unit geographical area of each state, i.e., mm/m^2, and shown in Fig. 3. The figure indicates that Himachal Pradesh has the lowest potential (7 mm/m^2) in repository of annual replenishable groundwater followed by Arunachal Pradesh (17 mm/m^2), and then Jammu & Kashmir (20 mm/m^2). These states comprise mountainous formations with very high topographical variation. The statewise picture of per capita availability of replenishable groundwater resources based on the population of year 2001 indicates (Fig. 4) that Delhi has the lowest per capita allocation (21 m^3/year) followed by Chandigarh (33 m^3/year) and then Himachal Pradesh (60 m^3/year).

AVAILABILITY VERSUS POLLUTION THREAT

A rise in groundwater pollution is commonly evident in almost every state in the country. Increasing concentrations of polluting substances coupled with their areal spread in the subsurface are posing a threat to the availability. The main causes of rise in groundwater pollution are due to one or more of the following reasons: (i) overuse of groundwater aquifers, (ii) improper disposal of solid and liquid wastes from human activities, (iii) presence of fertilizer and pesticide related chemical toxins in irrigation return flow, (iv) occurrence of toxic material of geogenic origin in the groundwater such as: arsenic and fluoride, (v) seawater encroachment in the coastal freshwater aquifers, (vi) influence of

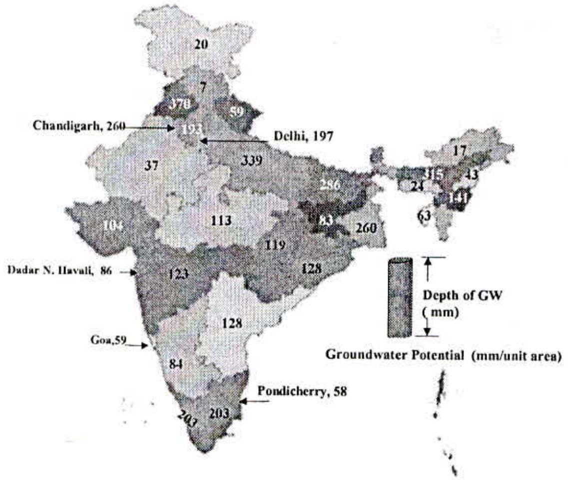

Fig. 3. Statewise potential of replenishable groundwater resources in terms of depth (mm) per unit area.

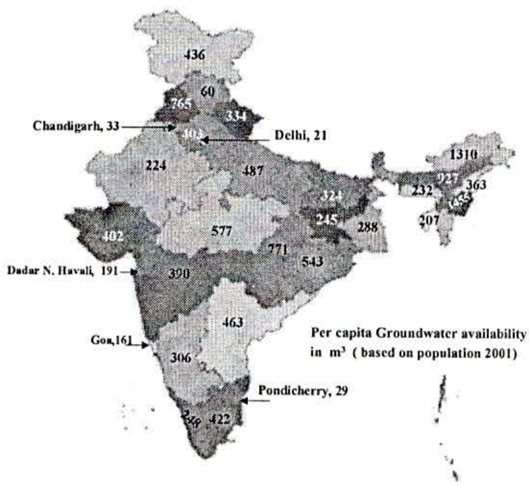

Fig. 4. Statewise per capita availability of replenishable groundwater resources (m^3/year) based on population of year 2001.

saline and alkaline layers of groundwater on the freshwater zones, etc (Ghosh and Sharma, 2006). In many areas, the level of groundwater pollution has reached serious concerns. For example; (i) occurrence of fluoride in excess of the permissible limit in parts of Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Chhatisgarh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal (Mehta, 2005), and occurrence of arsenic in the groundwater aquifer in West Bengal, have created a major public health crisis, (ii) salinity problems in groundwater aquifers in parts of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, M.P., Chhatisgarh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, U.P., NCT Delhi is posing threat to salinity ingress of freshwater aquifers, (iii) pollution of groundwater in many urban and industrial cities by the seepage of leached material is rendering groundwater unfit for human use, (iv) occurrence of excessive concentration of iron in groundwater aquifers in parts of Assam, Bihar, Orissa, Rajasthan, Tripura, and West Bengal is creating significant health hazards. Unlike surface water bodies, a groundwater aquifer once contaminated is difficult to restore back to its original state.

Any groundwater augmentation scheme launched in water deficit regions also helps in mitigating the possibility of pollution; however, in severely polluted aquifers the whole purpose of groundwater augmentation would get defeated. Thus, while planning a large groundwater augmentation scheme to enhance the water availability in a water deficit region, it is essential to consider the prevailing condition of the aquifer. The concept of donor and donee in ground water, i.e., storage of water in an adjacent aquifer to meet the primary needs of a region under threat of pollution and supplying the water as per the demand, could be an alternate solution to such a situation. Figure 5 illustrates the saline and alkaline aquifers in different states of the country. It is clearly evident from this figure that a major part of Rajasthan, parts of Gujarat, Uttar Pradesh, Karnataka, Andhra Pradesh, Tamilnadu, Maharastra, Madhya Pradesh, Orissa, Delhi, Punjab, Haryana and West Bengal are underlain by saline and alkaline water. To examine the scenario of groundwater availability over the next two decades, statewise projection of per capita availability of replenishable groundwater resources (in m ^{3}/year) for the years 2005 and 2025 has been shown in Fig. 5. The value in numerator indicates availability in the year 2025, while that in denominator represents the value for the year 2005. Using these projected values of the per capita groundwater availability and considering the average per capita groundwater requirement to be 391.7 m^3/year in 2025, one can make a rough assessment of (i) states that would require additional quantity of groundwater reserves to fulfill future requirements, and (ii) states that would have adequate storage of groundwater.

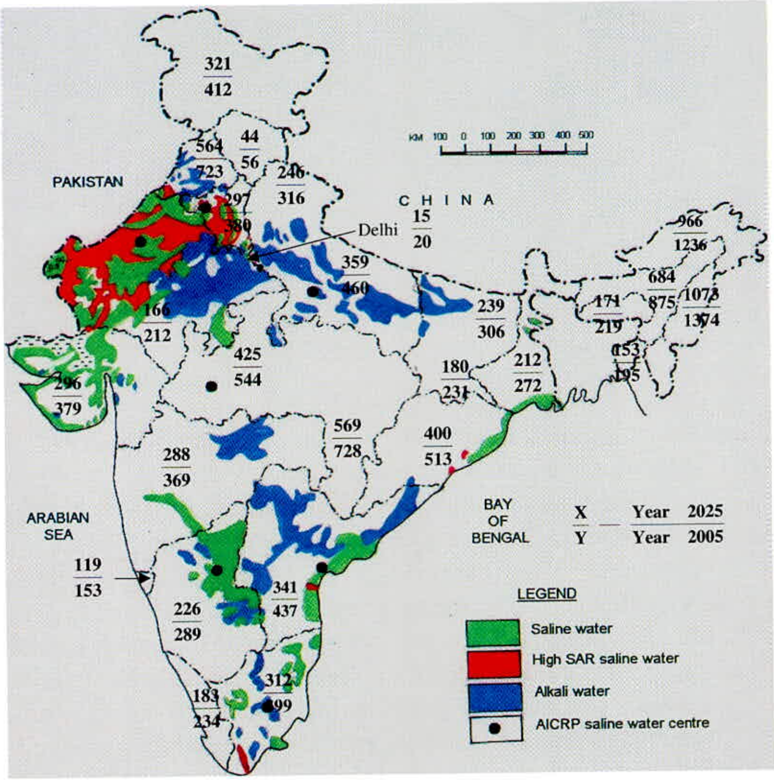

Fig. 5. Saline and alkaline aquifers in different states of India, and the statewise projected per capita availability of replenishable groundwater resources in year 2005 and year 2025. Value shown in numerator corresponds to the year 2025, and in denominator corresponds to the year 2005.

SCOPE FOR AUGMENTATION OF GROUNDWATER RESOURCES

Out of the average annual rainfall of 1170 mm, about 135 mm (11.5%) is available in the form of average groundwater potential; about 585.7 mm (50%) is available in the form of surface runoff through different rivers. Out of the 585.7 mm of average surfacewater potential, about 216.3 mm of surface water is utilizable; balance 369.4 mm of surfacewater runoff goes as unutilized. To meet the groundwater requirement of 391.7 m^3/year/capita by the year 2025, the average groundwater potential has to be raised to 168.3 mm against the available annual replenishable potential of 135 mm, i.e., an average rise of 33.3 mm over the available potential of 135 mm.

Statewise additional per capita requirement by the year 2025 over the available replenishable groundwater is given in Fig. 6. Part of the unutilized surface water aş given in Table 2 could be the probable source of water to augment groundwater in the respective state. However, an alternate scientific and economically viable scheme would be necessary for the deficit states or regions where the aquifers are under a threat from pollution hazards as shown in Fig. 5. For example, in fresh-saline aquifers haphazard pumping induces saltwater upconing that may eventually lead to aquifer degradation. Implementation of skimming well technology in such fresh-saline aquifers permits users to pump fresh groundwater without drawing inferior quality of water. It may be noted that unplanned development of a threatened aquifer further aggravates the problem of supply and demand. Thus, enhancement of supply to meet the demand without exposing an aquifer to the additional risk of pollution should be the main focus in achieving the objectives of groundwater governance.

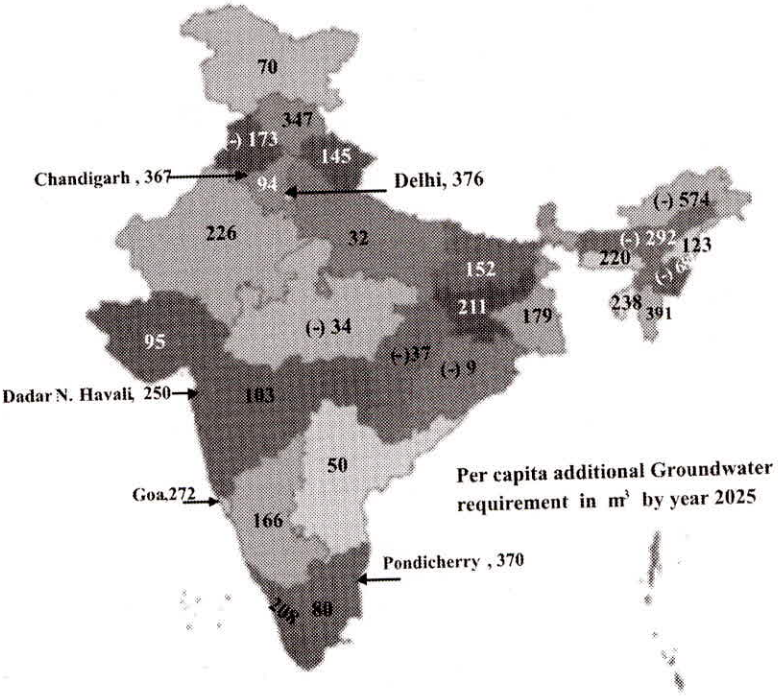

Fig. 6. Statewise per capita additional groundwater requirement (m^3/year) by the year 2025. Minus sign indicates possibility of surplus groundwater over the per capita groundwater requirement.

SUMMARY

Good governance addresses the proper allocation and management of resources to respond to collective problems. In case of ground water, suitable management of supply and demand could bring solution to the numerous water related problems affecting the masses in general. The supply-side management mainly depends on the hydrological and hydrogeological aspects, while demand side is governed by the uses and users of groundwater, and is regulated by the hydrogeology of the aquifer besides socio-economic status of the users.

Considering hydrologic, hydrogeologic, and demographic homogeneity on a regional scale, the availability of replenishable groundwater resources in terms of depth per unit area, and change in per capita availability over different years have been analyzed and projected on an approximate basis. The scope for augmentation of groundwater resources to meet the additional requirement in the coming years has been discussed. It has been pointed out that alternate scientific and economically viable schemes would be necessary for the deficit states or regions where the aquifers are under threat from pollution hazards. The concept of donor and donee in pollution threatened aquifers has also been suggested. The analysis presented could aid in development of suitable groundwater management plan to address governance issues related to groundwater.

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