Estimation of replenishable groundwater resources of India and their status of utilization

Rana Chatterjee and Raja Ram Purohit*

Dynamic groundwater resources of India have been estimated using groundwater resource estimation methodology-1997. The methodology uses the water-level fluctuation technique and empirical norms for recharge estimation. The groundwater utilization is also estimated. The stage of groundwater development is worked out and assessment units are categorized based on the stage of groundwater development and long-term water-level trend. The annual replenishable groundwater resources of India is 433 billion cubic metre (bcm) and net annual groundwater availability is 399 bcm. The annual groundwater draft for 2004 was 231 bcm. Thus the overall stage of groundwater development is 58%. Out of 5723 assessment units in the country, 4078 are 'safe' and 839 are 'over-exploited'. The rest fall under 'semi-critical' and 'critical' category. Over-exploitation is more prevalent in northwestern, western and Peninsular India. Eastern India has good potential for future groundwater development. Considering the changing groundwater scenario, re-assessment of groundwater resources needs to be carried out at regular intervals. This would require further strengthening of the available database.

Keywords: Groundwater draft, rainfall infiltration factor, replenishable groundwater resources, specific yield, water-level fluctuation.

GROUNDWATER resource is a replenishable but finite resource. Rainfall is the principal source of recharge, though in some areas, canal seepage and return flow from irrigation also contribute significantly to the groundwater recharge. Groundwater resource comprises of two parts – dynamic resource in the zone of water-table fluctuation which reflects seasonal recharge and discharge of aquifers and static resource below this zone, which remains perennially saturated[1]. National Water Policy, 2002 of India stresses that 'exploitation of groundwater resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity'[2]. Thus dynamic groundwater resource is essentially the exploitable quantity of groundwater, which is recharged annually. It is also termed as annually replenishable groundwater resource.

In India, dynamic groundwater resources are estimated jointly by the Central Ground Water Board (CGWB) and State governments at periodical intervals. The latest estimates of dynamic resources are based on groundwater resource estimation methodology-1997 (commonly known as GEC-1997). The basic principle followed in this methodology is the estimation of annual groundwater recharge from rainfall and other sources, including irrigation, water bodies and artificial recharge, determination of present status of groundwater utilization and categorization of assessment units based on the level of groundwater utilization and long-term water level trend[3]. These estimations are widely used in formulating various groundwater development and management plans. The present article describes the methodology used in the groundwater resource estimation and the results of the latest country-wide assessment. It also discusses the future strategies on groundwater resource estimations.

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Availability of groundwater in India

Availability of groundwater is widely variable across the length and breadth of the country. The great Himalayan ranges in the north act a rainshed divide ushering rainfall in the Indian plains, the most important source of groundwater recharge in the country. The consolidated rock formations of the Himalayas are not particularly conducive to groundwater. However, the Bhabars and Terais at the foothills of the lofty mountain chain act as a potential groundwater recharge zone for the aquifer systems downhill. The deeper confined aquifers in these formations display flowing artesian conditions. The Indo-Gangetic alluvium occurring in the foredeeps of the Himalayas forms the most productive and extensive multi-aquifer system in India. The tubewells tapping granular horizons in this belt have recorded an yield up to 75 litres per second (lps). Potential aquifers down to more than 600 m deep have been explored in this region. Semi-consolidated formations with moderate groundwater yield occur in narrow valleys or structurally faulted basins in the belts fringing the peninsular region adjacent to the Ganga plain, Narmada and Tapi valleys, coastal belt and in parts of Rajasthan, Gujarat and also parts of the northeastern region. Open wells in these sedimentary formations have yield in the range 1–5 lps. Basalt lava flows of the Deccan Traps in Central India in Maharashtra, Madhya Pradesh and Gujarat have usually poor to moderate potential. Dug wells and dug-cum-borewells are the most common groundwater structures generally yielding between 1 and 20 lps. Peninsular India is mostly characterized with consolidated formations like granites–gneisses and other igneous and metamorphic rock assemblages. Groundwater in these formations occurs in weathered and fractured zones. Open wells generally record a yield between 1 and 9 lps and borewells tapping deeper fracture zones have occasionally recorded high yields, up to 30 lps. The occurrence of groundwater in these terrains is, however, site-specific unlike alluvial areas. The coastal areas having thick alluvium deposits form the prospective aquifer systems. Deep tubewells tapping multi-aquifers in these tracts have yield potential up to 60 lps. Groundwater development in these coastal areas is, however, associated with the risk of sea-water intrusion. Groundwater yield potentials in different parts of the country are presented in Figure 1.

Methodology for estimation of dynamic groundwater resource

Dynamic groundwater resources of the states are estimated following GEC-1997, which has been formulated by a committee of experts working in the field of groundwater. The committee was constituted by the Government of India, drawing members from various Central and State agencies, academic and scientific institutions and NABARD. GEC-1997 is based on seasonal estimation of groundwater recharge in an assessment unit through lumped water balance method during monsoon season and empirical norms during non-monsoon season. The time period for groundwater recharge estimation is for a groundwater year (12 calendar months), which commences with the onset of monsoon of one calendar year and culminates just before the monsoon season for the next calendar year. In areas experiencing southwest monsoon, it is between June/July of one calendar year and May/June of the next calendar year. In areas with northeast monsoon, it is between October of one calendar year and September of the next calendar year.

The advantages of GEC-1997 are as follows:

(a) The method is a lumped approach and therefore relatively simple to use.

(b) It is suitable with regard to the data normally available from groundwater-level monitoring programmes of State and Central agencies.

(c) Application of water-level fluctuation (WLF) method for recharge estimation during monsoon season. The WLF method which is more commonly referred to in the international literature as water table fluctuation (WTF) method, provides actual field evidence of recharge to groundwater. The area represented by recharge rates (fluxes) arrived through the WLF method ranges from tens of square metres to several hundred or thousand square metres. These recharge fluxes can be spatially integrated over large areas, which is important for large-scale water resources assessment[4]. Thus this method is suitable for regional estimates. The time period represented by the recharge estimates using the WLF method ranges from event (short time) scale to the length of the hydrographic record[4]. Thus there is scope for assessment both at short time intervals as well as for longer periodical intervals using WLF method.

(d) Since monsoon rainfall is the most significant contributor to groundwater recharge in our country, rainfall recharge during the monsoon season is estimated using two methods – WLF method and rainfall infiltration factor (RIF) method.

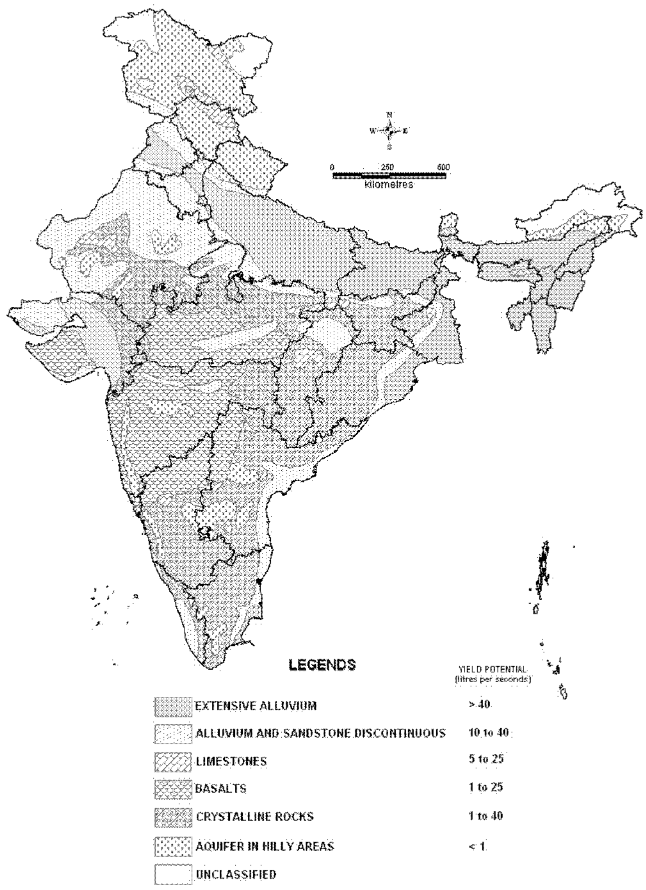

Figure 1. Major aquifer systems of India[10].

Assessment procedure

Assessment of replenishable groundwater resources and categorization involves the steps shown in Figure 2.

Steps for the estimation of annual replenishable groundwater resources and categorization of assessment units/sub-units are presented in Figure 3.

Governing equations for recharge estimations

- Recharge estimation during monsoon season

(1) WLF approach

Possible recharge during monsoon season after deducting natural discharges is the sum total of change in storage and gross draft during the monsoon season.

$$R = S + D_G = h*Sy*A + D_G, \quad (1)$$

where R is the recharge during monsoon, S the change in storage ($S = h*Sy*A$), D_G the gross draft during monsoon season, h the water-level fluctuation between pre-monsoon and post-monsoon, Sy the specific yield and A the area of assessment.

(2) Normalization of rainfall recharge

$$R_{rfi} = R - R_c - R_{sw} - R_{gw} - R_{wc} - R_t, \quad (2)$$

$$= h*Sy*A + D_G - R_c - R_{sw} - R_{gw} - R_{wc} - R_t, \quad (3)$$

where R_{rfi} is the rainfall recharge during monsoon season for ith particular year, R_c the recharge from canal seepage during monsoon season (in command areas) for ith particular year, R_{sw} the recharge from surface water irrigation during monsoon season (in command areas) for ith particular year, R_{gw} the recharge from groundwater irrigation during monsoon season for ith particular year, and R_{wc} the recharge from water conservation structures during monsoon season for ith particular year and R_t the recharge from tanks during monsoon season for ith particular year.

Rainfall recharge is normalized for estimating recharge corresponding to the normal monsoon rainfall using the following linear relationship between recharge and rainfall – (i) $R = ar$, where R is the rainfall recharge during monsoon season, r the monsoon season rainfall and a is a constant. Normal rainfall recharge is obtained as

$$R_{rf}(\text{normal}) = R_i*r(\text{normal})/r_i, \quad (4)$$

or (ii) $R = ar + b$, where R is the rainfall recharge, r the rainfall, and a and b are constants. This is a linear regression analysis involving following equations:

$$a = [N\Sigma r_i R_i - \Sigma r_i \Sigma R_i]/[N\Sigma r_i^2 - (\Sigma r_i)^2], \quad (5)$$

$$b = [\Sigma R_i - a\Sigma r_i]/N. \quad (6)$$

Normal rainfall recharge is computed as $R_{rf} = a*r(\text{normal}) + b$.

(3) RIF

$$R_{rf} = F*A*\text{normal rainfall during monsoon season}, \quad (7)$$

where R_{rf} is the rainfall recharge during monsoon, F the rainfall infiltration factor and A the area of assessment unit.

(4) Percentage difference

$$PD = [(R_{rf}(\text{normal, WLF method}) - R_{rf}(\text{normal, RIF method}))/R_{rf}(\text{normal, RIF method})]*100, \quad (8)$$

where PD is the difference between WLF and RIF estimate expressed as a percentage of RIF estimate.

If PD is within ± 20%, $R_{rf}(\text{normal}) = R_{rf}(\text{WLF})$.
If PD is <–20%, $R_{rf}(\text{normal}) = 0.8*R_{rf}(\text{RIF})$.
If PD is >20%, $R_{rf}(\text{normal}) = 1.2 * R_{rf}(\text{RIF})$.

$$R(\text{normal}) = R_{rf}(\text{normal}) + R_c + R_{sw} + R_{gw} + R_{wc} + R_t. \quad (9)$$

- Recharge estimation during non-monsoon season.
  Rainfall recharge – Using RIF approach.
  Recharge from other sources – Using norms recommended in GEC-1997 or values obtained through field studies.
  Total recharge is the sum of rainfall recharge and recharge from other sources.

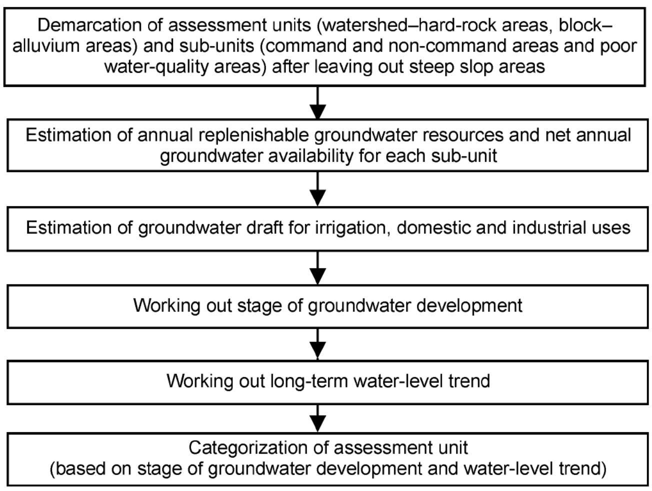

Figure 2. Assessment and categorization of replenishable groundwater resources.

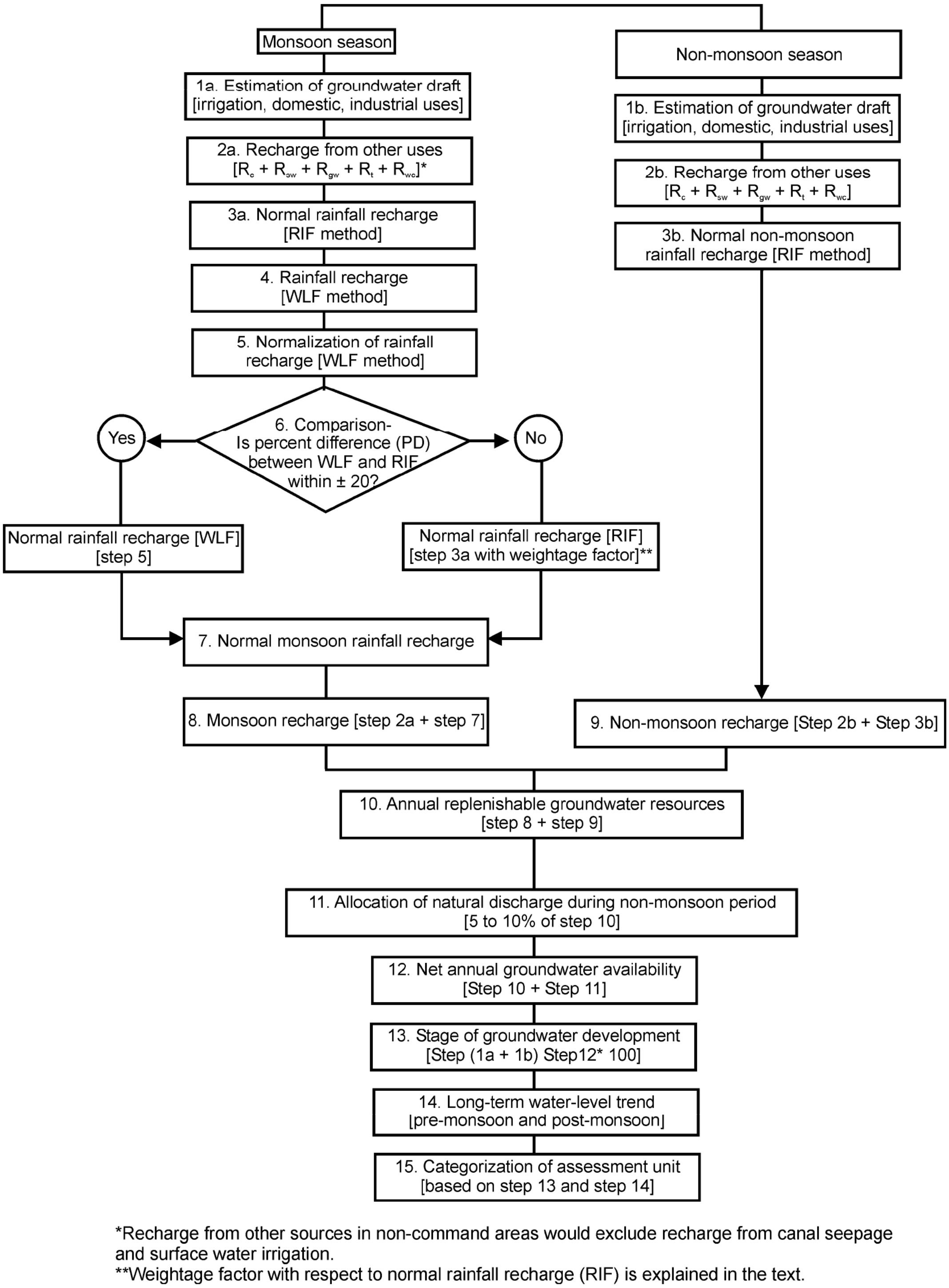

Figure 3. Steps for estimation and categorization of annual replenishable groundwater resources (based on Rajagopalan *et al.*[5]).

- Annual recharge = Recharge during monsoon + recharge during non-monsoon.

Categorization of assessment units

The assessment units are categorized according to the status of groundwater utilization and water level trend (Table 1).

Organizational procedures involved in assessment

At the initiative of the Government of India, the State Level Working Groups/Technical Committees on groundwater estimation were revived to re-estimate the groundwater resource potential based on the guidelines of GEC-1997. The respective State-level committees are mostly headed by the State Secretary-in-Charge of Water

Table 1. Criteria for categorization of assessment units

Stage of groundwater development	Significant long-term decline		Categorization
	Pre-monsoon	Post-monsoon	
≤70%	No	No	Safe
>70% and ≤90%	No	No	Safe
	Yes/no	No/yes	Semi-critical
>90% and ≤100%	Yes/no	No/yes	Semi-critical
	Yes	Yes	Critical
>100%	Yes/no	No/yes	Over-exploited
	Yes	Yes	Over-exploited

Resources and include members from State Ground Water Departments, Regional Office of CGWB, NABARD, State Irrigation Departments, Water Supply Departments, Agriculture Departments, etc. The State Groundwater Departments and CGWB jointly undertook the task of resource assessment during 2004–05. The entire exercise was based on the present state of knowledge of the hydrogeological set-up of the respective areas. The estimation was initiated through the collection of data required for resources estimation, followed by adoption of parameters for recharge and draft computations. Based on the available data, various components of groundwater recharge and draft and categorization of assessment units were computed. Technical guidance for state-level estimates and national-level compilation was provided by a central-level technical group known as R&D Advisory Committee on Ground Water Estimation. The Committee is headed by the Chairman, CGWB and draws members from CGWB, State agencies and NABARD.

Database and norms used for resource computations

The water-level data for a period of around a decade of approximately 45,000 monitoring stations of the CGWB and State Ground Water Departments (SGWD) were used in resource computations. Rainfall data were collected from India Meteorological Department. The normal rainfall data are the long-term (generally 30–50 years) averages. Hydrogeological set-up of the assessment units is based on studies carried out by the CGWB and SGWD. Data on dimensions and water release of canals and irrigation schedules were collected from the irrigation and flood control departments of the State governments and cropping pattern data were provided by state agriculture departments. The number of groundwater structures used for irrigation was obtained from Minor Irrigation Census conducted by the Ministry of Water Resources, Government of India, as well as by the state governments. Information on dependency on groundwater for domestic uses was provided by PHE departments, whereas the information on groundwater use by industries was obtained from the Department of Industries.

The recharge computations are mainly based on various norms recommended by GEC-1997. Specific yield data were either arrived through field studies, including long-duration pumping tests and dry season groundwater balance (in hard-rock areas) or adopted from the norms recommended by GEC-1997, which were derived from the various water-balance studies carried out by CGWB, SGWDs and academic/research institutions. Similarly, norms for rainfall infiltration factor were compiled through analysis of rainfall/recharge relationships worked out in various water-balance studies. Norms for return-flow factors from irrigation (both surface water and groundwater), canal seepage factor and seepage factor of water bodies were formulated based on the studies carried out in water-balance projects, investigations by State Irrigation Departments and experimental studies carried out by research institutes.

The range of values of parameters considered for groundwater resources assessments in various states is summarized in Table 2.

Groundwater draft computations are based on following procedures.

Irrigation draft: Based on unit draft method, wherein unit draft of various structures, adopted either using norms recommended in GEC-1997 or through field studies, are multiplied with the number of structures according to the Minor Irrigation Census report. In some cases, crop water requirement method has been applied, wherein crop water requirement is multiplied with area irrigated to compute groundwater consumption.

Domestic draft: Either based on unit draft method or on consumption pattern method, wherein per capita requirement and dependency on groundwater sources to meet the requirement are multiplied with population to arrive at groundwater consumption.

Industrial draft: Most of the states estimated this component jointly along with domestic draft based on water requirement of the population. In a few cases, estimation was based on unit draft of various structures or water requirement by various industrial units and the dependency on groundwater sources to meet the requirement.

Table 2. Values of parameters considered for recharge estimation of groundwater resources in India

Formation	Specific yield	Rainfall infiltration factor
Rainfall recharge		
Unconsolidated formations		
Alluvial sediments	0.04–0.20	0.08–0.25
Semi-consolidated formations		
Shale, sandstone	0.01–0.15	0.03–0.14
Limestone	0.01–0.03	0.06–0.07
Laterite	0.01–0.04	0.05–0.08
Consolidated formations		
Granites, gneisses, schists	0.01–0.04	0.03–0.11
Quartzites	0.015–0.03	0.06–0.08
Basaltic rocks	0.01–0.025	0.06–0.12
Massive crystalline rocks	0.002–0.015	0.01–0.08

Source	Type	Seepage factor/return flow factor
Recharge from other sources		
Canal	Unlined canal	15–30 ham/day/million m^2 of wetted area depending on soil type
	Lined canal	20% of above value for unlined canals
Irrigation	Surface water	0.10–0.50 depending on cropping pattern and depth to water level; shallow water level and paddy-cropped areas have higher return flow factor
	Groundwater	0.05–0.45 depending on cropping pattern and depth to water level; shallow water level and paddy-cropped areas have higher return flow factor
Water bodies		1.4 mm/day based on average area of water spread

From CGWB[6].

Table 3. Norms used for draft computations of groundwater resources of India

Use	Structure	Unit draft
Irrigation	Dug well	0.2–0.9 ha m/yr
	Dug well with pumpset	1.5 ha m/yr
	Shallow tubewell	0.8–3.0 ha m/yr
	Deep tubewell	1.6–25 ha m/yr
	Bore well	1–3 ha m/yr
Domestic	Dug well	0.35–1.5 ha m/yr
	Shallow tubewell	0.65–3 ha m/yr
	Bore well	0.65–2.5 ha m/yr
	Per capita consumption	40–135 lpcd depending on rural and urban population Dependency on groundwater – 10–100%

The average norms adopted for various groundwater uses are given in Table 3.

Volumetric assessment of annual replenishable groundwater resources

The annual replenishable groundwater resource for the entire country is 433 billion cubic metre (bcm)[6]. The overall contribution of rainfall to the country's annual replenishable groundwater resource is 67% and the share of other sources, including canal seepage, return flow from irrigation, seepage from water bodies and water conservation structures taken together is 33%. In Andhra Pradesh, Delhi, Haryana, Jammu & Kashmir, Jharkhand, Punjab, Tamil Nadu, Uttar Pradesh, Uttarakhand and the UT of Puducherry, the contribution of other sources is more than the national average of 33%, mainly because of canal seepage and intensive irrigation. The southwest monsoon being the most prevalent contributor of rainfall in the country, about 73% of the country's annual replenishable groundwater recharge takes place during the kharif period of cultivation. Keeping 34 bcm as the allocation for natural discharge during non-monsoon season, the net

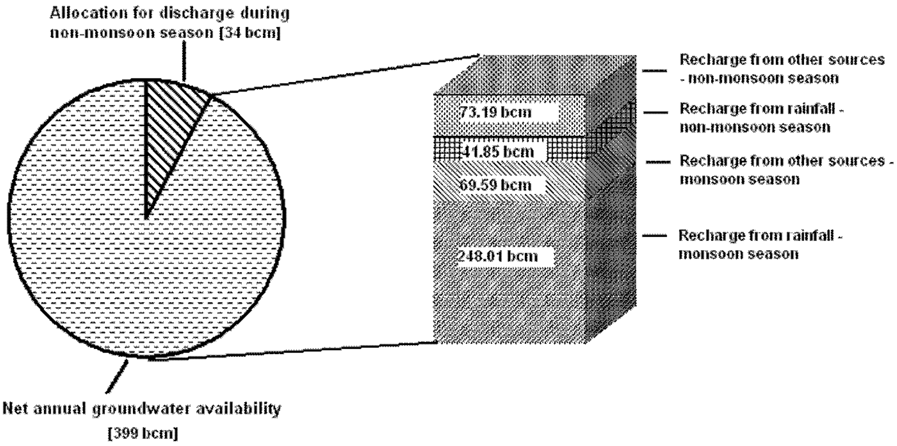

Figure 4. Annual replenishable groundwater resources.

annual groundwater available for utilization for the entire country is 399 bcm (Figure 4). State-wise groundwater resources availability, utilization and categorization of over-exploited and critical blocks are given in Table 4.

Groundwater utilization pattern in India (as on 2004)

The total annual groundwater draft is 231 bcm, out of which 213 bcm is used for irrigation and 18 bcm is for domestic and industrial use. In general, the irrigation sector remains the main consumer of groundwater (92% of total annual groundwater draft for all uses; Figure 5). In Chhattisgarh, Delhi, Goa, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Kerala, the northeastern states of Manipur, Meghalaya, Mizoram, Nagaland and Tripura, Orissa, Sikkim, and the Union Territories of Dadra & Nagar Haveli, Daman & Diu, Lakshadweep and Puducherry, groundwater draft for domestic and industrial purposes is more than 15%, which is comparatively higher than the national aggregate figure of 8%.

The overall stage of groundwater development in the country is 58%. The stage of groundwater development is high in the states Delhi, Haryana, Punjab and Rajasthan, and UT of Daman & Diu and Puducherry, where the overall stage of groundwater development is more than 100%. In the peninsular states of Andhra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra and Tamil Nadu, the general scarcity of sustainable water supply has led to over-stress on the groundwater regime. Since most of the area in this region is occupied by hard-rock terrains, limited availability of groundwater has resulted in growing number of over-exploited blocks/mandals/taluks. The average stage of groundwater development in these states is also high. Parts of Uttar Pradesh and Uttarakhand also have high stage of groundwater development. In the states of Bihar, Orissa, West Bengal and the valley areas of Assam and Tripura in the North-east, there is ample scope for groundwater development since the stage of groundwater development in major parts of these states is lower and there are only few blocks/taluks having high stage of groundwater development (critical/over-exploited). In the states of Chhattisgarh, Goa, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Arunachal Pradesh, Manipur, Meghalaya, Mizoram and Nagaland and UTs of Andaman & Nicobar Islands, Dadra & Nagar Haveli, though the stage of groundwater development is lower, considering the prevailing hydrogeological situations, the groundwater development should be taken up with caution on site-specific basis. In hard-rock states like Chhattisgarh, Jharkhand, etc. occurrences of groundwater are limited to weathered and fractured zones, while in the hilly states like Jammu & Kashmir, northeastern states, etc. availability of water is restricted to the valley portions only. In islands like the Andaman & Nicobar, groundwater development is associated with the risk of saline-water intrusion.

Out of 5723 assessed administrative units (blocks/taluks/mandals/districts), 4078 are ‘safe’, 550 are ‘semi-critical’, 226 are ‘critical’, and 839 units are ‘over-exploited’ (Figure 6). The areas of the remaining 30 units are completely covered by saline groundwater. The number of over-exploited and critical administrative units was significantly higher (more than 15% of the total assessed units) in Andhra Pradesh (where categorization was done up to sub-unit level, i.e. within a mandal – command and non-command-wise), Delhi, Gujarat, Haryana, Karnataka, Punjab, Rajasthan and Tamil Nadu, and also the UTs of Daman & Diu and Puducherry.

Spatial variation in resource estimates

Volumetric estimates are dependent on the areal extent of the assessment unit. Thus, relative comparison of recharge and draft of different assessment units based on volumetric estimates is not possible. Hence in this article,

Table 4. State-wise groundwater resources availability, utilization and categorization of assessment units in India

States/union territory	Annual replenishable groundwater resource	Natural discharge during non-monsoon season	Net annual groundwater availability	Annual groundwater draft	Stage of groundwater development (%)	Categorization of assessment areas (number)	
						Over-exploited	Critical
State							
Andhra Pradesh	36.50	3.55	32.95	14.90	45	219	77
Arunachal Pradesh	2.56	0.26	2.30	0.0008	0.04	0	0
Assam	27.23	2.34	24.89	5.44	22	0	0
Bihar	29.19	1.77	27.42	10.77	39	0	0
Chhattisgarh	14.93	1.25	13.68	2.80	20	0	0
Delhi	0.30	0.02	0.28	0.48	170	7	0
Goa	0.28	0.02	0.27	0.07	27	0	0
Gujarat	15.81	0.79	15.02	11.49	76	31	12
Haryana	9.31	0.68	8.63	9.45	109	55	11
Himachal Pradesh	0.43	0.04	0.39	0.12	30	0	0
Jammu & Kashmir	2.70	0.27	2.43	0.33	14	0	0
Jharkhand	5.58	0.33	5.25	1.09	21	0	0
Karnataka	15.93	0.63	15.30	10.71	70	65	3
Kerala	6.84	0.61	6.23	2.92	47	5	15
Madhya Pradesh	37.19	1.86	35.33	17.12	48	24	5
Maharashtra	32.96	1.75	31.21	15.09	48	7	1
Manipur	0.38	0.04	0.34	0.002	0.65	0	0
Meghalaya	1.15	0.12	1.04	0.002	0.18	0	0
Mizoram	0.04	0.004	0.04	0.0004	0.90	0	0
Nagaland	0.36	0.04	0.32	0.009	3	0	0
Orissa	23.09	2.08	21.01	3.85	18	0	0
Punjab	23.78	2.33	21.44	31.16	145	103	5
Rajasthan	11.56	1.18	10.38	12.99	125	140	50
Sikkim	0.08	0.00	0.08	0.01	16	0	0
Tamil Nadu	23.07	2.31	20.76	17.65	85	142	33
Tripura	2.19	0.22	1.97	0.17	9	0	0
Uttar Pradesh	76.35	6.17	70.18	48.78	70	37	13
Uttaranchal	2.27	0.17	2.10	1.39	66	2	0
West Bengal	30.36	2.90	27.46	11.65	42	0	1
Total states	432.42	33.73	398.70	230.44	58	837	226
Union territory (UT)							
Andaman & Nicobar	0.330	0.005	0.320	0.010	4	0	0
Chandigarh	0.023	0.002	0.020	0.000	0	0	0
Dadra & Nagar Haveli	0.063	0.003	0.060	0.009	14	0	0
Daman & Diu	0.009	0.0004	0.008	0.009	107	1	0
Lakshadweep	0.012	0.009	0.004	0.002	63	0	0
Puducherry	0.160	0.016	0.144	0.151	105	1	0
Total UTs	0.597	0.036	0.556	0.181	33	2	0
Grand total	433.02	33.77	399.25	230.62	58	839	226

Source: CGWB[6].

volumetric estimates of annual groundwater recharge and draft (as calculated jointly by CGWB and state governments) have been divided by the area of the assessment unit to arrive at estimates per unit area. Maps on estimates per unit area (ha) have been generated to present the relative situation of recharge and draft across the country (Figures 7–9). Though the actual assessment unit is the block/taluka, etc. considering the ease of handling a smaller database and to reduce the complexity of the maps, these maps were prepared based on district-level figures of groundwater assessment as given by the CGWB[6].

Groundwater recharge is significantly high in the Indus–Ganga–Bramhputra alluvial belt in the North, East and North East India where rainfall is plenty and thick piles of unconsolidated alluvial formations are conducive for recharge. Recharge per unit area (ha) in these regions varies from 0.28 to 1.35 m (Figure 7). The coastal alluvial belt also has relatively high recharge, in the range 0.16–0.40 m. In western India, particularly Rajasthan and parts of western Gujarat which have arid climate, the annual recharge is scanty, mostly up to 0.10 m. Similarly, in major parts of the southern peninsular India, particularly in south Maharashtra, Karnataka and western

Andhra Pradesh, annual recharge is less, only up to 0.10 m. This is primarily because of comparatively low infiltration and storage capacity of the rock formations prevailing in the region. The remaining part of Central India is mostly characterized by moderate recharge in the range of 0.10–0.28 m.

Groundwater draft is quite high in northwestern India, in Punjab, parts of Haryana and western Uttar Pradesh, as also in the eastern parts of West Bengal (Figure 8). In these areas, annual groundwater draft is in the range of 0.35–2.12 m, mostly used for irrigation purposes. In greater parts of Uttar Pradesh and West Bengal, annual groundwater draft is in the range of 0.10–0.35 m. The northern parts of Tamil Nadu are characterized by groundwater draft between 0.10 and 0.35 m while parts of Kerala and Karnataka have groundwater draft between 0.10 and 0.16 m. Groundwater draft is low (up to 0.04 m) in Orissa, parts of Karnataka, coastal Andhra Pradesh, the arid regions of Rajasthan, the hilly regions of North East India and in the Jharkhand and Chhattisgarh belt. In the remaining parts of the country, annual groundwater draft is in the range of 0.04–0.10 m.

Figure 9 presents spatial variation of stage of groundwater development at the district-level. It reveals that in major portions in the states of Punjab, Haryana, Delhi, western Rajasthan, western Madhya Pradesh adjoining Rajasthan as well as parts of Peninsular India in western Karnataka and Tamil Nadu, groundwater resource is

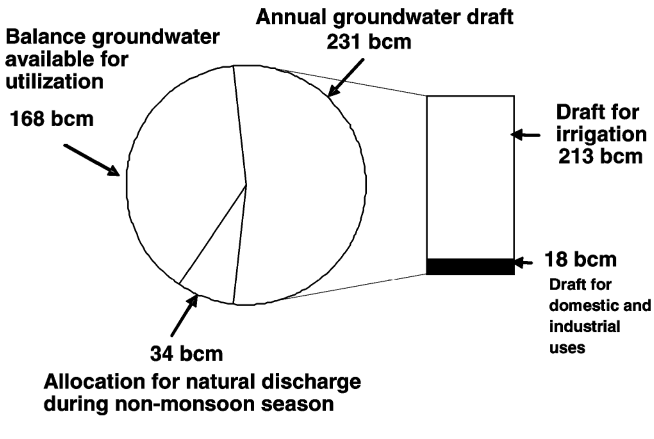

Figure 5. Status of groundwater utilization in India as on 2004.

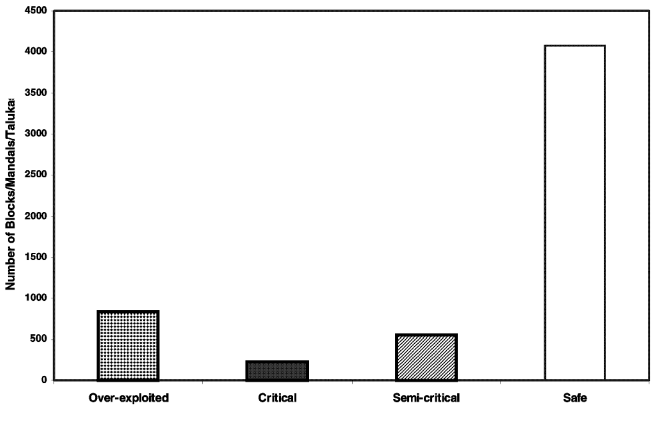

Figure 6. Categorization of assessment units in India.

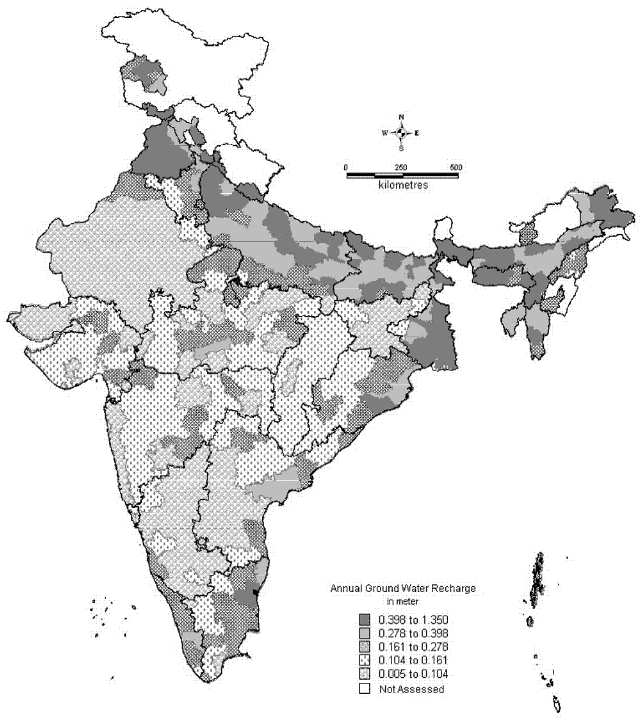

Figure 7. Annual groundwater recharge scenario in India (CGWB[6]).

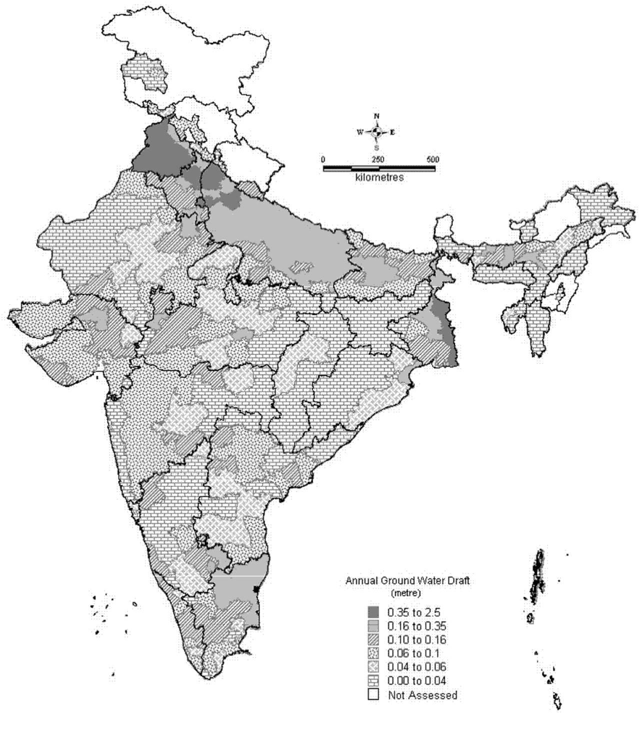

Figure 8. Annual groundwater draft scenario in India (from CGWB[6]).

over-exploited (more than 100%). Groundwater development is also high (between 70 and 100%) in the remaining parts of Rajasthan, Punjab and Haryana, in western Gujarat, western Uttar Pradesh, in eastern parts of West Bengal and in parts of Tamil Nadu, and southern parts of Andhra Pradesh adjoining Tamil Nadu/Karnataka. In major parts of the country however, groundwater development is moderate, within 70%. Very low groundwater development, below 10%, has taken place in the hilly areas of North East India and the forested belt covering eastern Maharashtra, south of Chhattisgarh and southwestern parts of Orissa.

Figure 10 depicts the spatial distribution of categorization of blocks/mandals/taluks across the country. In contrasts to Figures 7–9, which present district-level estimates, Figure 10 is the block-level map. Therefore, it presents micro-level variation within district-level estimates as shown in the previous maps.

Conclusion and recommendations

(i) Groundwater resource computations based on GEC-1997, as indicated in this article, present an aggregate situation with respect to assessment of exploitable groundwater resource and status of its utilization at the block level. However, considering the heterogeneity of the hydrogeological set-up normally encountered in the field and complexity of the groundwater hydraulics, this first level of quantification should be followed by micro-level assessments. Such assessments should be based on detailed studies involving field estimations of various recharge and discharge parameters. Since detailed investigations are time-consuming, areas for micro-level studies need to be prioritized. Over-exploited and critical areas would be the natural preference in the priority list. Areas with quality problem should also be taken up on priority basis for detailed groundwater assessment[7].

(ii) GEC-1997 is essentially a simplistic lumped parameter system approach. Some of the inflow and outflow components of water balance like evaporation and evapotranspiration, inflow and outflow across the assessment boundary, baseflow, etc. have been ignored in this methodology, since database on these components is not readily available with the state governments at present. Efforts should be made for the generation of database of these components, so that at micro-level assessment, complete water balance of the assessment unit can be attempted.

(iii) Norms of various parameters used in recharge estimations were derived based on the results of the studies on water balance, soil moisture budget, mathematical modelling, recharge estimation through isotope techniques, etc. There is a need to replicate similar R&D studies on recharge estimations using various methods like the ones mentioned above and also other methods like chloride mass balance, baseflow hydrograph separation method, etc. This would help in refining the norms of various recharge parameters which is necessary to

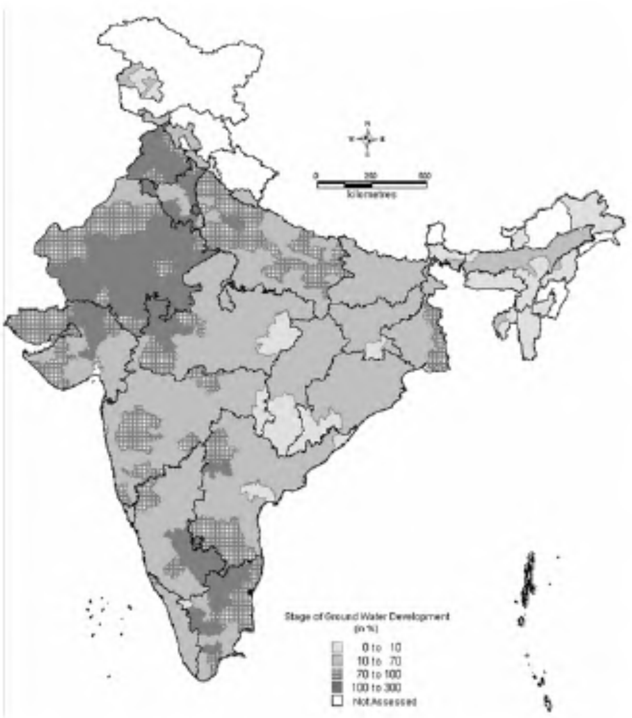

Figure 9. Stage of groundwater development in India (based on CGWB[6]).

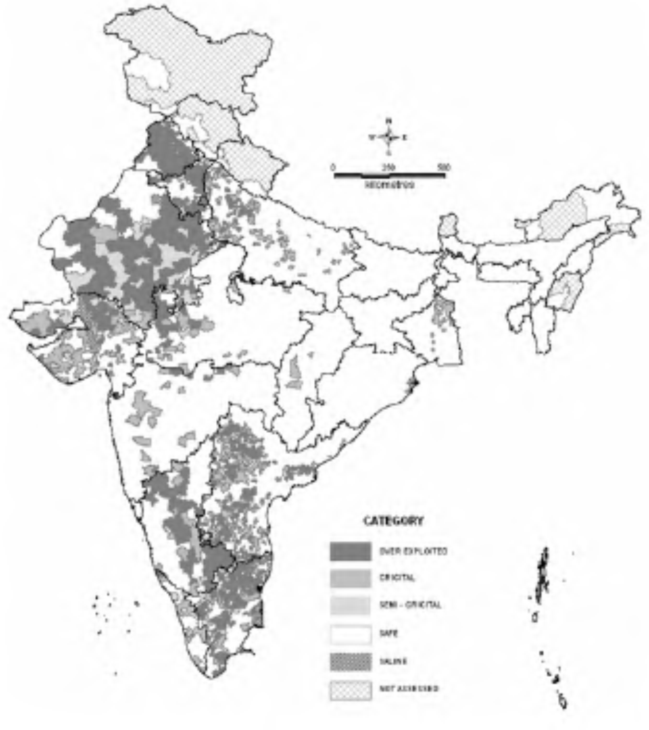

Figure 10. Categorization of blocks/mandals/talukas (as on 2004) (from CGWB[6]).

address the diversity in hydrogeology, geomorphology and agro-climatic conditions existing within the macro geographic units of our country.

(iv) Groundwater resources estimation is a continuing process, since the natural recharge and discharge pattern of the aquifer changes with changing groundwater scenario. Therefore, there is an urgent need for the formulation of a long-term action plan for periodical re-assessment of groundwater resources of the country. The intervening periods between successive re-assessment should be devoted to further strengthening of the database. These would include intensified monitoring of the measured data like water level, rainfall, canal discharge, well census, baseflow, etc. and special studies on estimation of parameters like specific yield, rainfall infiltration factor, canal seepage factor, return flow factor, etc.[8]. The generation of database should be followed with pilot estimation studies in identified assessment units and finally with country-wide re-assessment.

(v) Considering the significance of categorization of assessment units in the groundwater management and regulation plans, an alternative concept based on GIS technique has been proposed for assessing the prevailing groundwater scenario of an area. Layers of various indices of groundwater resources like surface elevation, normal rainfall, forest cover, hydrogeology, canal command and water-level trend can be superimposed to obtain a composite map demarking the areas vulnerable from point of view of groundwater depletion. Proper weightages need to be assigned for various indices according to their influence on groundwater recharge. Each index would also have several categories of points according to the magnitude of the particular component. The final categorization would be obtained from the sum-total of the points for various indices. This approach would address the issue of regular updation of categorization of the areas and can be used as a cross-check of GEC-1997 estimates. The advantage of this approach is threefold. (1) Most of the layers like surface elevation, normal rainfall, forest cover and hydrogeology are a one-time exercise. Many of them are already available in digitized format. Thus, only water-level maps need to be updated regularly. (2) Maps of surface elevation, normal rainfall, hydrogeology, etc. are prepared after considerable studies. Therefore these maps are fairly accurate. (3) Since water-balance components like groundwater draft, baseflow, etc. are not used in this method, database-related errors are minimized. However, at present, this is simply a concept and a detailed method needs to be evolved based on pilot studies.

(vi) In view of increasing demand of groundwater, systematic assessment of the additional sources of groundwater needs to be carried out. In the hilly terrain, where springs are an important source of water supply, exploitable quantity of spring discharge needs to be estimated. In the shallow water-table areas, where in spite of regular groundwater extraction, the water level does not decline, the sustainable yield[9] of the aquifers needs to be determined. In the Indo-Gangetic alluvial belt where multi-layered aquifer systems exist, studies need to be carried out to find out the sustainable yield of the deeper aquifers.

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