Alarming scarcity of water in India

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In this article the assessment of utilizable water resources of India, based on various studies by the government, has been reviewed and analysed. The analysis yields that the utilizable water resources are overestimated in various studies, ranging from 66% to 88%. We have estimated the utilizable water resources as 668 billion cubic metre (BCM) against 1110 BCM of CWC, 1209 to 1255 BCM of NCIWRDP and 1122 BCM of the National Water Policy of India. The consequence will be alarming as the projected demand of even 897 BCM, corresponding to low demand scenario, cannot be met even after full development of utilizable water resources. The analysis also revealed that almost all the basins would become water-deficit, and raises a big question about the availability of water through inter-basin transfer. It is also shown that the groundwater has already been overexploited as far back as 1997–98. Therefore, contrary to the previous studies like those of NCIWRDP, CWC, etc., water scarcity is alarming and calls for urgent action before it becomes unmanageable.

Keywords: Assessment, management, utilizable water resources, water availability and scarcity.

INDIA is facing a serious problem of natural resource scarcity, especially that of water in view of population growth and economic development. Water being a prime natural resource, a basic human need and a precious national asset, its use needs appropriate planning, development and management. But surprisingly, the recent report of the National Commission for Integrated Water Resources Development Plan (NCIWRDP)[1], states: 'Taking into account the water availability and the requirements till the year 2050, the Commission concludes that there is no need to take an alarmist view'. This made us suspect the findings of the Commission, as there is all-round problem of water scarcity, groundwater depletion, etc. This motivated us to investigate whether there are any misfindings in the estimates of utilizable water resources.

Since water resources data are classified, and even a recent article[2] on water resources of India has not given any new estimates of utilizable water resources but only replicated the tables or figures of NCIWRDP, Central Water Commission (CWC)[3], etc., the previous original studies carried out by various government organizations and commissions, running into several volumes, were studied and analysed. The analysis revealed that the utilizable water resources of India are much lower and are overestimated in various studies ranging from 66% to 88%. Water scarcity will be alarming as the projected demand[1] of even 897 billion cubic metre (BCM), corresponding to low demand scenario, cannot be met even after full development of the water resources. After analysing the previous studies, we have also provided new estimates of utilizable water resources for each river basin. We have also identified the basins as water-deficit or surplus depending upon their water requirements and utilizable water resources. It is also shown that the groundwater is already being overexploited since 1997–98.

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Utilizable surface water

The average annual virgin (natural) flow at the terminal point of a river is generally reckoned as the water resources potential of the river basin[4]. The assessment of water resources of India from various studies[1,3–7] ranges between 1673 and 1953 BCM. The latest estimate of total water resources of India as assessed by NCIWRDP is 1952.87 BCM, but this cannot be fully put to beneficial use because of topographical and other constraints.

Utilization[1] of water resources can be taken as the quantum of withdrawable water from its place of natural occurrence, such as river or groundwater. Withdrawablity of water largely depends on the existence/possibility of storage and diversion structures and land availability.

About 80–90% of the river flows occur during four months of the monsoon season. For the use of water during the non-monsoon seasons, there is a need to create storage capacities in reservoirs and tanks. The total storage built up in the projects completed up to 1995 is about 174 BCM. From projects under construction, another 76 BCM of storage capacity is likely to be added. From identified future projects another 132 BCM can be added, making a total of 382 BCM. An additional live storage capacity of 3 BCM is estimated to be created through medium projects[1]. All these aggregate to a total of 385 BCM.

The NCIWRDP also states that the CWC has estimated the utilizable surface water in each river basin considering suitable sites/locations for diversion and for storage structures. The CWC has estimated the utilizable water in each river basin from surface structures as 690.31 BCM (Table 1). NCIWRDP and the National Water Policy[8] have

also adopted the utilizable surface flow as 690.31 BCM, as estimated by CWC.

Utilizable surface water resources have been estimated in the past also. The Irrigation Commission[5] summed up the country's utilizable surface water resources as 666 BCM. Rao[6] suggested that the quantum should be 50% of the country's available annual run-off (1645 BCM). The National Commission on Agriculture (NCA)[7] estimated the utilizable quantity from surface water to be 700 BCM.

Groundwater resources

Groundwater is an annually replenishable resource and its availability is non-uniform in space and time. A complexity of factors – hydrogeological, hydrological and climatological – control groundwater occurrence and movement. Only freshwater was included and saline areas were not included in the assessment of groundwater resources in various studies. Further, annually replenishable component of groundwater was considered for use in developmental planning. The replenishable groundwater resource was essentially a dynamic one, which is replenished annually or periodically by rainfall, irrigation return flow, canal seepage, tank seepage, etc.

Dynamic groundwater or replenishable groundwater

The Irrigation Commission reported that no systematic quantitative assessment of groundwater has been made so far[5]. However, a rough assessment of groundwater resources has been attempted by Raghava Rao[5]. The Irrigation Commission report summed up in the end: 'the draft, at present, on account of domestic and industrial uses is estimated to be of the order of 65 BCM. The groundwater resources available for irrigation and future draft for domestic and industrial wells, may be of the order of 204 BCM'.

The NCA in its report[7] assessed the total groundwater resource of India as 670 BCM, of which 450 BCM gets regenerated during the non-monsoon period as surface water. This 670 BCM included 500 BCM as natural recharge from precipitation. On full development of water resources the groundwater is estimated to increase to 850 BCM, of which 450 BCM is again assumed to be available as regenerated surface water. The utilizable groundwater extraction was assessed as 350 BCM.

The CWC[3] adopted the possible utilization from groundwater as 418.54 BCM, which was taken from the estimates of CGWB (see Table 1).

Based on a large amount of data with detailed analysis, the CGWB in 1994–95 estimated[9] the replenishable groundwater as 431.9 BCM. The CGWB also mentions results of previous studies, including those of the NCA[7] in its report. The figure of 431.9 BCM is taken as the sum of the recharge of 342.4 BCM from rainfall and the additional recharge of 89.5 BCM from the canal irrigation system. A minimum provision of 15% of total groundwater resources was kept for domestic, industrial and other uses. The remaining 85% can be made available for irrigation,

Table 1. Basin-wise annual utilizable water resources[3]

Basin	Estimated utilizable flow, *excluding groundwater* (BCM)	Utilizable groundwater (CGWB assessment 1983–84) (BCM)	Total utilizable flow (BCM)
Indus (up to border)	*46.000*	17.810	63.810
Ganga	*250.000*	172.010	422.010
Brahmaputra	*24.000*	20.820	46.15
Barak		1.330	
Godavari	*76.300*	44.980	121.280
Krishna	*58.000*	24.620	82.620
Cauvery	*19.000*	10.420	29.420
Pennar	*6.858*	5.350	12.208
East-flowing rivers between Mahanadi and Pennar	*13.110*	11.690	24.800
East-flowing rivers between Pennar and Kanyakumari	*16.732*	21.080	37.812
Mahanadi	49.990	18.200	68.190
Brahmani and Baitarni	18.297	7.890	26.187
Subarnarekha	6.813	2.850	9.663
Sabarmati	1.925	4.380	6.305
Mahi	3.095	4.440	7.535
West-flowing rivers of Kutch Saurashtra, including Luni	14.980	12.610	27.590
Narmada	*34.500*	13.000	47.500
Tapi	*14.500*	6.730	21.230
West-flowing rivers from Tapi to Tadri, including Tadri	11.936	8.980	20.916
West-flowing rivers from Tadri to Kanyakumari	24.273	7.740	32.013
Area of inland drainage in Rajasthan desert	–	1.330	1.330
Minor river basins draining to Bangladesh and Burma	–	0.280	0.280
Total	690.309 say 690	418.540	1108.849 say 1110

but only 90% of it has been taken as utilizable groundwater resources for irrigation[9], leaving 10% to maintain river ecology. This amounts to around 91.5% of the total groundwater resources as utilizable. Accordingly, the utilizable groundwater resources can be taken as 313.3 BCM (0.915 × 342.4) from natural recharge and 81.9 BCM (0.915 × 89.5) from recharge due to canal irrigation system[9], making the total utilizable groundwater resources to be about 395.2 BCM.

The NCIWRDP[1] has also adopted the replenishable groundwater resources as 431.9 BCM as given in CGWB report[9] and the total utilizable groundwater resources as 396 BCM.

Water resources at a glance

It is observed that most of the studies estimate the water resources of India as 1880 BCM, while the total utilizable water resources vary considerably. The NCA has estimated[7] the total utilization as 1050 BCM. The total utilizable water resources of India, according to the CWC[3] are 1110 BCM (Table 1), while NCIWRDP[1] estimated the same as 1086 BCM plus additional return flows (123 BCM for low-demand scenario or 169 BCM for high-demand scenario). Thus the total utilizable water resources of 1086 BCM would be further enhanced to 1209 or 1255 BCM, depending upon low- or high-demand scenario, according to NCIWRDP[1].

Utilizable water resources – analysis

For the first time, the Irrigation Commission[5] has broadly summed up the utilizable surface water resources of the country as 666 BCM[5]. The Commission[5] also observed that 'surface and groundwater resources' are interlinked. Therefore, integrated studies are needed to cover both the resources'[5], but no efforts were made by the Commission in this direction. Rao[6] suggested that the quantum of utilizable water resources of India should be 50% of the available run-off.[6]

In our opinion, among all the Commissions, it was only the NCA[7] that approached the problem of finding out the utilizable flows after taking into account the interactions between the ground- and surface water. Within the limitations of the available data, the NCA[7], through detailed water-balance studies, has estimated that the utilizable surface flows aggregate to 700 BCM and groundwater to about 350 BCM, after full development of water resources. Of the total utilization of 700 BCM from surface water, 250 BCM was estimated through the storages having total live storage capacity of 350 BCM, with the estimated evaporation losses from various storages as 100 BCM. The non-monsoon utilization of surface flows was expected to be 450 BCM as a result of the groundwater natural recharge, regenerating itself as surface water. The extraction from groundwater, called as utilizable groundwater, was estimated as 350 BCM, which would be available after full water-resources development. Thus according to NCA[7], the utilizable water-resources from surface flows aggregate to the 700 BCM and from groundwater to about 350 BCM, making the total utilizable water resources to be 1050 BCM.

Regeneration from groundwater to river, in the form of surface water, was considered as a part of utilizable flows from the surface water, besides the reservoir storage. The NCA has assumed the recharge from the natural precipitation as regenerated groundwater flow into the rivers and estimated it to be 450 BCM in the absence of any detailed study. Therefore, it may be concluded that the total utilizable surface water resources, according to the NCA, aggregated to about 700 BCM [250 BCM (storage–reservoir losses) plus 450 BCM regenerated groundwater flow into the rivers]. The details of utilizable flows[7] are given in Table 2. The additional 350 BCM from groundwater was estimated to be available due to irrigation recharge after full water-resources development.

The CWC[3] reassessed the total utilizable water resources of the country as 1108.849 BCM; 690.309 BCM from surface structures plus 418.54 BCM from groundwater (Table 1). However, no details are given about the 690 BCM of utilizable surface water by CWC, but it is mentioned in the report that the NCA report[7] is one of the sources in preparing estimates of basin-wise annual utilizable water resources. According to the storage estimates available at that time, the CWC[3] had considered the expected total live storage capacity as 334 BCM, but no figure was given for reservoir losses.

In order to find out a reasonable explanation for the 690 BCM, we investigated and analysed the previous studies, including those of the NCA. After the analysis it was found that the CWC had directly adopted the figures of utilizable surface water from the NCA report[7]. The total live storage capacity as considered by the NCA was 350 BCM, and it was reduced by 100 BCM to account for reservoir losses. Following the NCA report[7], the reservoir losses corresponding to 334 BCM can be estimated to be 95 BCM. It would give utilizable water from reservoirs as

Table 2. Basin-wise annual utilizable flow[7]

River	Utilizable flow* (BCM)
Indus basin	*46*
Ganga basin	*250*
Brahmaputra basin, including Barak	*24*
Mahanadi and other east-flowing rivers up to Godavari	91
Godavari, Krishna, and other east-flowing southern rivers	*190*
West-flowing rivers south of Tapi	30
Narmada and Tapi	*49*
West-flowing rivers north of Narmada	20
Total	700

*Excluding evaporation losses from reservoirs.

Table 3. Comparison of utilizable flows of identical basins

Basin	Utilizable flow[7] (BCM)	Estimated utilizable flow, *excluding groundwater*[3] (BCM)
Indus basin	46	46
Ganga basin	250	250
Brahmaputra basin, including Barak	24	24
Godavari, Krishna and other east-flowing southern rivers	190	190
Godavari, Krishna, Cauvery, Pennar, east-flowing rivers between Mahanadi and Pennar, and east-flowing rivers between Pennar and Kanyakumari		(76.3 + 58.0 + 19.0 + 6.858 + 13.11 + 16.732)
Narmada and Tapi	49	49 (34.5 + 14.5)

239 (say 240) BCM. The reduction in utilizable water, due to the difference in live storage corresponding to the NCA and CWC estimates[7,3], can be estimated as 10 BCM (250–240). Therefore, it reduces the figure of 700 BCM of utilizable flow of NCA estimate[7] to 690 BCM of the CWC report[3].

The utilizable flows of identical river basins (highlighted in Tables 1 and 2) as estimated by the CWC and NCA are compared in Table 3. It is evident from Table 3 that the CWC had directly adopted the values of the NCA. As already discussed, the estimates of utilizable flows of the NCA also included the interaction of surface and groundwater in the form of regenerated groundwater flows of 450 BCM into the rivers. These flows were taken as the natural groundwater recharge due to precipitation by the NCA. It is clear from Table 1 that the CWC had ignored this fact that estimated utilizable flows were taken after excluding the groundwater. The CWC added 418.54 BCM as utilizable groundwater to the estimated utilizable flows and estimated total utilizable flows as 1110 BCM.

A combined figure of 418.54 BCM was taken as utilizable groundwater by the CWC without giving the break-up of natural recharge from rainfall and additional recharge due to the irrigation system. If the entire utilizable groundwater of 418.54 BCM was to be added to the utilizable surface flows, then the latter should have been reduced by 450 BCM by the CWC. Therefore, the total utilizable flows should have been estimated as 658.54 BCM (690 – 450 + 418.54) in place of adding 418.54 to 690 BCM.

Hence, it is clear that the CWC has overestimated the total utilizable flows to a total of 1110 BCM, which should have been reduced to 658.54 BCM.

Since then, subsequent reports of the CWC or NCIWRDP have taken the values from the CWC report[3], and therefore adopted the over-estimated figures of utilizable flows. The report of the National Water Policy of India has also adopted the over-estimated figure of 1122 BCM as total utilizable water resources.

Water requirement

Efforts have been made to estimate the water use and likely water requirements in the future by various investigators[1,3,6,7]. Recent projections of water requirements made by the NCIWRDP are based on detailed studies. The water use in 1997 and water requirements in the future till the year 2050 have been worked out by the NCWIRDP. Water use in 1997–98 was estimated as 629 BCM, and projected water requirements in 2010, 2025 and 2050 were estimated as 694, 784, 973 BCM under low-demand, and 710, 843, 1180 BCM under high-demand scenarios respectively. These estimated water requirements also included evaporation losses. As discussed earlier, the utilizable water resources have been estimated after deducting evaporation losses[7]. Therefore, the corrected water use in 1997 was 593 BCM, and projected water requirements in 2010, 2025 and 2050 have been estimated as 652, 734, 897 BCM under low-demand, and 668, 793 and 1104 BCM under high-demand scenario respectively, after deducting the evaporation losses. It may be noted that the NCIWRDP has already taken into account the increased efficiencies, yields, etc. while estimating the water requirements.

It is obvious that the total water requirement of 897 BCM, corresponding to low-demand scenario cannot be met even after full development of the utilizable water resources, as the corrected utilizable water resources corresponding to the CWC have been modified to 658.54 BCM.

We have also worked out the total utilizable flows, basin-wise. In order to calculate the return flows, the basin-wise total water requirements were taken from the NCIWRDP report[1]. However, the report gave only basin-wise irrigation water requirements and the break-up for other uses in the basin was assumed proportionally, as shown in Table 4. We have estimated the total utilizable flows from surface and groundwater, and identified the water deficit and surplus basins.

Estimate of utilizable water resources

Based on the above analysis, it is fairly appropriate to assume that the utilizable water resources can be taken as the sum of the storages (excluding reservoir losses), and as discussed earlier, 91.5% of total replenishable groundwater resources consisting of the natural groundwater recharge and total return flows to groundwater. In addition, return flows to the surface water were also added in the utilizable water resources.

In order to calculate the return flows, it is reasonable to assume the achievable efficiencies according to the NCIWRDP report[1], based on practical experience. Accordingly, the overall irrigation efficiencies were assumed[1] as 60% from surface water and 75% from groundwater by the year 2050. Total return flows were taken as 24% from surface water and 15% from groundwater of the percentage of gross irrigation requirement (GIR). The projected national average values of GIR (or delta)[1] in 2050 were 0.61 m from surface water and 0.49 m from groundwater. Around 90% of return flows from irrigation are expected to contribute to groundwater source and balance 10% to surface water source. Return flows from domestic uses were assumed as 50% of supplies, out of which 85% would go to surface water and balance 15% to groundwater[1]. Return flows from industrial uses were estimated at an overall average of 50% of the supplies, all of which would go to the surface water. The priorities of water uses were in accordance with those of the National Water Policy of India[8], starting from drinking, irrigation, hydropower, ecology, industries, navigation and other uses, depending upon the water availability. In view of this, the utilizable water resources were estimated by us as given below.

The total possible live storage capacity has been worked out as 385 BCM by the CWC[10], which was also adopted by the NCIWRDP[1]. The estimate of 385 BCM of live storage capacity was taken in the present study as the ultimate live storage capacity by 2050. We have some reservations about the feasibility of creating this quantity of live storage capacity and it will also be reduced due to sedimentation. Reservoir losses were taken on an average to be about 20% of live storages based on the CWC report[4], reducing the useful live storage capacity to 308 BCM. The utilizable natural recharge was taken as 312.9 BCM (91.5% of 342 BCM).

Therefore, the utilizable water flows of India were estimated as 621 BCM (308 + 313) without considering return flows. In addition, 91.5% of recharges due to irrigation system and return flows from other withdrawals were also considered as additional utilizable groundwater. The return flows to surface water were considered as additional utilizable surface water. Our basin-wise estimates of the utilizable water flows are given in Table 4. The total water use/required for all the uses in 2050 corresponding to low-demand scenario[1] were considered in Table 4, while allocating the water for different uses according to priorities[8] and correspondingly the return flows were also calculated. The calculations made in Table 4, in order to estimate the utilizable flows, are self-explanatory.

Basin-wise total utilizable surface water and groundwater, including return flows are given in columns 37 and 38 respectively (of Table 4). It may be noted that the summation of column 39 gives the total utilizable water as about 752 BCM, while the deficits/surpluses of column 40 add to around –145 BCM. However, it will give a false impression since the surplus utilizable water of one basin is not available to another basin at present. Therefore, the total utilizable water is reduced from 752 to 668 BCM (Table 4) and net utilizable water basin-wise is given in column 41. Net utilizable water for a basin is taken as total utilizable water (column 39) if the basin is water-deficit; otherwise it is taken as total water requirement of the basin (column 8). Therefore, the total water deficit would be increased from 145 to 229 BCM. The deficits would further worsen, if the assumed efficiencies and yields are not achieved in practice.

The water requirements[1] and utilizable water resources are also compared basin-wise in Table 4. A basin is identified as water-surplus (+) basin if the total utilizable water resources, including return flows in the basin are more than the water requirements, else it is identified as water-deficit (–). Table 4 shows that most of the basins are water-deficit, even if low-demand scenario is considered by 2050. It would also raise a big question on the possible availability of utilizable water of the order of 200–250 BCM, as considered by the NCIWRDP through inter basin transfer schemes. The scenario becomes worse if high water demands are considered for the analysis. Following similar calculations as done for the low-demand scenario, the total deficit increases to 396 BCM for high-demand scenario.

The utilizable water resources of 668 BCM, as estimated by us, were compared with the estimates of CWC[3] and NCIWRDP[1]. The CWC estimate[3] is 1110 BCM and that of NCIWRDP[1] ranges from 1209 to 1255 BCM. Thus, these are overestimated compared to our estimate of utilizable water resources by 66–88%. All these estimates are based on the conventional water resources development. It is clear that the total water requirement of even 897 BCM in 2050, corresponding to low-demand scenario cannot be met even after full development of the utilizable water resources, which we estimate as 668 BCM. In fact, the impact of water scarcity in India can also easily be felt at present, as interstate water disputes are already worsening and causing social and political problems. This is in contradiction to the recommendations of the NCIWRDP[1].

It may be noted that the planning, development and management of water resources of India is based on the utilizable water resources of 1122 BCM, according to the National Water Policy of India[8], while we estimate the utilizable water resources as 668 BCM. In absolute terms, the overestimation in the utilizable water resources is of the order of 454 BCM (1122–668) or about 1.68 times of 668 BCM. This requires an urgent attention of the policy makers and also to evolve a mechanism for the monitoring and implementation of the policies.

Groundwater development – already overexploited

According to the CGWB[9], groundwater development was of the order of 31.92% in 1995, and it suggested a huge

Table 4. Utilizable water, total utilizable water including return flows and water deficit/surplus basins of India (as proposed by the authors)

Sl no.	River basin	Live storage capacity[1] (includes additional 3 BCM on proportional basis) (BCM)	Replenishable groundwater resource (GWR) from normal natural recharge[1] (BCM)	Utilizable water (col. 3 × 0.8 + col. 4 × 0.915) (see text) (BCM)	Population in the year 2050 (low projections) distributed proportionately[1] (million)	Total water use/requirement for all uses in the year 2050 (low demand)[1] (BCM)	Total water use/requirement excluding evaporation losses (76 BCM) in 2050 (low demand) (BCM)	Gross irrigated area from surface water (SW) (GIA_{SW}) in 2050 (low demand)[1] (mha)	Gross irrigated area from ground water (GW) (GIA_{GW}) in 2050 (low demand)[1] (mha)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Indus	16.68	14.29	26.419	66.93	72.45	69.15	5.054	5.261
2	Ganga–Brahmaputra–Meghna basins								
2a	Ganga	84.18	136.47	192.21	569.97	387.22	370.58	26.625	22.498
2b;c	Brahmaputra; Meghna (Barak)	67.37	34.24	85.22	56.39	54.27	40.95	1.482	2.958
3	Subernarekha	3.93	1.68	4.68	15.18	8.83	8.05	0.622	0.334
4	Brahmani–Baitarani	13.83	3.35	14.13	15.65	15.99	13.26	1.497	0.582
5	Mahanadi	25.04	13.64	32.51	42.49	49.93	44.98	3.214	2.63
6	Godavari	38.74	33.48	61.63	86.26	82.44	74.78	5.396	5.617
7	Krishna	42.72	19.88	52.37	97.12	80.39	71.94	5.875	3.601
8	Pennar	2.53	4.04	5.72	15.50	12.84	12.34	0.805	0.453
9	Cauvery	8.22	8.79	14.62	46.80	31.42	29.79	1.114	1.237
10	Tapi	11.62	6.67	15.40	23.64	15.13	12.83	0.832	0.603
11	Narmada	23.98	9.38	27.76	23.48	27.26	22.52	1.766	0.87
12	Mahi	5.17	3.5	7.34	16.77	8.94	7.92	0.543	0.41
13	Sabarmati	1.57	2.9	3.91	16.93	7.01	6.70	0.3	0.316
14	West-flouring rivers of Kachchh, Saurashtra and Luni	8.10	9.1	14.81	46.65	27.00	25.40	0.709	1.439
15	West-flouring rivers south of Tapi	25.05	15.55	34.26	93.29	38.57	33.62	2.077	0.848
16–18	East-flouring rivers between Mahanadi and Godavari East-flouring rivers between Godavari and Krishna East-flouring rivers between Krishna and Pennar	3.97	12.82	14.91	37.70	21.36	20.58	1.742	0.82
19, 20	East-flouring rivers between Pennar and Cauvery East-flouring rivers south of Cauvery	1.45	12.65	12.74	71.88	28.90	28.61	1.681	1.121
21	Area of North Laddakh not draining into Indus	0.00	0	0.00	0.00	0.00	0.00	0	0
22, 23	Rivers draining into Bangladesh Rivers draining into Mayanmar	0.31	0	0.25	3.35	2.85	2.79	0.06	0.059
24	Drainage areas of Andaman, Nicobar and Lakshadweep islands	0.00	0	0.00	0.00	0.00	0.00	0	0
	Total	384.46	342.43	620.891	1346.0	972.80	896.8	61.394	51.657
	Say	385	342	621	1346	973	897	61	52

(*Contd...*)

Table 4. (*Contd...*)

Proposed irrigation water use/ requirement in 2050 from SW (low demand)[1] (col. 9 × 0.61 m) (BCM)	Proposed irrigation water use/requirement in 2050 from GW (low demand)[1] (col. 10 × 0.49 m) (BCM)	Total domestic water use/ requirement (90 BCM), 2050 distributed proportional to the population (low demand)[1] (BCM)	Water use/ requirement other than domestic and irrigation in 2050 (low demand) (col. 8, cols 11–13) (BCM)	Water use/ requirement for power in 2050 (distributed proportionately) (low demand) (col. 14 × 63/ 179.177) (BCM)	Water use/ requirement for ecology in 2050 (distributed proportionately) (low demand) (col. 14 × 20/179.177) (BCM)	Water use/ requirement for industries in 2050 (distributed proportionately) (low demand) (col. 14 × 81/179.177) (BCM)	Water use/requirement for navigation and other uses in 2050 (distributed proportionately) (low demand) (col. 14 × 15/179.177) (BCM)	Provision for domestic uses from GW at 15% (col. 4 × 0.15) (see text) (BCM)	Balance available from GW for irrigation use (col. 4 × 0.915– col. 19) (BCM)
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
30.829	25.779	4.475	8.069	2.837	0.901	3.648	0.675	2.144	10.932
162.413	110.240	38.111	59.817	21.032	6.677	27.041	5.008	20.471	104.400
9.040	14.494	3.770	13.648	4.799	1.523	6.170	1.143	3.770	27.559
3.794	1.637	1.015	1.607	0.565	0.179	0.727	0.135	0.252	1.285
9.132	2.852	1.047	0.226	0.080	0.025	0.102	0.019	0.503	2.563
19.605	12.887	2.841	9.647	3.392	1.077	4.361	0.808	2.046	10.435
32.916	27.523	5.768	8.575	3.015	0.957	3.876	0.718	5.022	25.612
35.838	17.645	6.494	11.968	4.208	1.336	5.410	1.002	2.982	15.208
4.911	2.220	1.036	4.174	1.467	0.466	1.887	0.349	0.606	3.091
6.795	6.061	3.130	13.808	4.855	1.541	6.242	1.156	1.319	6.724
5.075	2.955	1.581	3.222	1.133	0.360	1.457	0.270	1.001	5.103
10.773	4.263	1.570	5.914	2.080	0.660	2.674	0.495	1.407	7.176
3.312	2.009	1.122	1.475	0.519	0.165	0.667	0.123	0.525	2.678
1.830	1.548	1.132	2.189	0.770	0.244	0.989	0.183	0.435	2.219
4.325	7.051	3.119	10.903	3.834	1.217	4.929	0.913	1.365	6.962
12.670	4.155	6.238	10.556	3.712	1.178	4.772	0.884	2.333	11.896
10.626	4.018	2.521	3.410	1.199	0.381	1.542	0.285	1.923	9.807
10.254	5.493	4.807	8.060	2.834	0.900	3.643	0.675	3.645	7.930
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.366	0.289	0.224	1.909	0.671	0.213	0.863	0.160	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
374.503	253.119	90.000	179.177	63.000	20.000	81.000	15.000	51.746	261.577
375	253	90	179	63	20	81	15	52	262

(*Contd...*)

Table 4. (*Contd...*)

Surplus or deficit of irrigation water from GW (col. 20–col. 12) (BCM)	Provision for domestic uses from SW (col. 13–col. 19) (see text) (BCM)	Balance available from SW for irrigation use (col. 3 × 0.80–col. 22) (BCM)	Surplus or deficit of irrigation water from SW (col. 23–col. 11) (BCM)	Irrigation water use from GW (use all the available GW, if basin is deficit with respect to SW) (see text) (BCM)	Irrigation water use from SW (use all the available SW, if basin is deficit with respect to GW) (see text) (BCM)	Combined water use for irrigation + domestic from GW (col. 25 + col. 19) (BCM)	Combined water use for irrigation + domestic from SW (col. 26 + col. 22) (BCM)	Available water to meet the demands other than domestic and irrigation (col. 5–col. 27–col. 28) (BCM)	Allocation for power (BCM)	Allocation for ecology (BCM)	Allocation for industries (BCM)	Allocation for navigation (BCM)
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
–14.847	2.332	11.012	–19.817	10.932	11.012	13.075	13.344	0.000	0.000	0.000	0.000	0.000
–5.841	17.640	49.701	–112.711	104.400	49.701	124.870	67.341	0.000	0.000	0.000	0.000	0.000
13.065	0.000	53.893	44.852	14.494	9.04	18.265	9.040	57.917	4.799	1.523	6.170	1.143
–0.351	0.763	2.382	–1.412	1.285	2.382	1.537	3.145	0.000	0.000	0.000	0.000	0.000
–0.289	0.544	10.518	1.386	2.563	9.492	3.065	10.036	1.026	0.080	0.025	0.102	0.019
–2.452	0.795	19.233	–0.372	10.435	19.233	12.481	20.028	0.000	0.000	0.000	0.000	0.000
–1.911	0.746	30.248	–2.668	25.612	30.248	30.634	30.994	0.000	0.000	0.000	0.000	0.000
–2.437	3.512	30.667	–5.171	15.208	30.667	18.190	34.179	0.000	0.000	0.000	0.000	0.000
0.871	0.430	1.594	–3.317	3.091	1.594	3.697	2.024	–0.001	0.000	0.000	0.000	0.000
0.663	1.811	4.768	–2.027	6.724	4.768	8.043	6.579	0.001	0.000	0.000	0.000	0.000
2.148	0.580	8.716	3.641	2.955	5.075	3.955	5.655	5.789	1.133	0.360	1.457	0.270
2.913	0.163	19.019	8.246	4.263	10.773	5.670	10.936	11.158	2.080	0.660	2.674	0.495
0.669	0.597	3.540	0.227	2.009	3.312	2.534	3.909	0.896	0.519	0.165	0.212	0.000
0.670	0.697	0.561	–1.269	2.219	0.561	2.654	1.258	–0.001	0.000	0.000	0.000	0.000
–0.090	1.754	4.729	0.404	6.962	4.437	8.327	6.191	0.292	0.292	0.000	0.000	0.000
7.741	3.905	16.131	3.461	4.155	12.67	6.488	16.575	11.202	3.712	1.178	4.772	0.884
5.789	0.598	2.579	–8.047	9.807	2.579	11.730	3.177	0.000	0.000	0.000	0.000	0.000
2.437	1.162	0.000	–10.255	7.930	0	11.575	1.162	–0.001	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
–0.289	0.224	0.026	–0.340	0.000	0.026	0.000	0.250	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.458	38.254	269.314	–105.189	235.043	207.570	286.789	245.824	88.279	12.615	3.911	15.387	2.811
8	38	269	–105	235	208	287	246	88	13	4	15	3

(*Contd...*)

Table 4. (*Contd...*)

Return flow (RF) to GW (see text) (BCM)	Return flow to SW (see text) (BCM)	Total replenishable GW including RF (col. 4 + col. 34) (BCM)	Total utilizable SW, including RF (col. 3 × 0.8 + col. 35) (BCM)	Total utilizable GW, including RF (col. 36 × 0.915) (BCM)	Total utilizable water both from SW and GW, including RF (col. 37 + col. 38) (BCM)	Deficit/surplus basin (col. 39–col. 8) (BCM)	Net utilizable water basin-wise (col 39, if col. 40 < 0, else col. 8) (BCM)
34	**35**	**36**	**37**	**38**	**39**	**40**	**41**
4.190	2.330	18.480	15.674	16.909	32.584	–36.569	32.584
27.688	18.956	164.158	86.297	150.204	236.502	–134.078	236.502
4.192	5.122	38.432	59.014	35.165	94.180	53.227	40.953
0.764	0.508	2.444	3.652	2.236	5.889	–2.164	5.889
2.475	0.762	5.825	11.824	5.330	17.154	3.898	13.257
5.776	1.826	19.416	21.854	17.766	39.620	–5.361	39.620
10.424	3.561	43.904	34.555	40.172	74.727	–0.054	74.727
9.164	3.724	29.044	37.903	26.575	64.478	–7.466	64.478
0.839	0.525	4.879	2.549	4.465	7.013	–5.327	7.013
2.172	1.545	10.962	8.125	10.031	18.155	–11.639	18.155
1.614	1.566	8.284	10.863	7.580	18.443	5.610	12.833
3.020	2.327	12.400	21.508	11.346	32.855	10.334	22.520
1.071	0.692	4.571	4.829	4.182	9.011	1.093	7.918
0.506	0.528	3.406	1.786	3.116	4.902	–1.797	4.902
2.132	1.536	11.232	8.019	10.277	18.296	–7.102	18.296
3.766	5.403	19.316	25.440	17.674	43.114	9.495	33.619
2.070	1.280	14.890	4.457	13.624	18.082	–2.493	18.082
1.431	2.162	14.081	3.323	12.884	16.207	–12.406	16.207
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.022	0.096	0.022	0.346	0.021	0.366	–2.422	0.366
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
83.316	54.451	425.746	362.019	389.558	751.576	–145.224	667.921
83	54	426	362	390	752	–229 +84 = –145	668

Note: Basin-wise water uses/requirements estimation. The basin-wise total water use/requirement and gross irrigated area from SW and GW are taken from the NCIWRDP[1]. But no basin-wise estimates of water uses/requirement for domestic, power, ecology, industries, navigation and other uses are given by the NCIWRDP[1]. The basin-wise estimates for all the uses are made by us proportionally as given in Table 4. The estimated water use/requirement of each basin if added together match with the total water use/requirement of that basin as given by the NCIWRDP[1].

Provision/allocation of water for different uses: The provision or allocation of water is made for different uses based on priorities suggested by the National Water Policy[8]. The order of priorities is drinking water, irrigation, power, ecology, industries, navigation and other uses.

Calculation of RF: (i) RF[1] generated @50% of domestic water use (col. 19 + col. 22); RF to GW @15% of {0.5 × (col. 19 + col. 22)}; RF to SW @85% of {0.5 × (col. 19 + col. 22)}

(ii) RF[1] generated from irrigation water use @15% of irrigation water use from GW + @ 24% of irrigation water use from SW; RF to GW @90% of (0.15 × col. 25 + 0.24 × col. 26); RF to SW @10% of (0.15 × col. 25 + 0.24 × col. 26)

(iii) RF[1] generated @50% industrial water use (0.50 × col. 32); RF to GW @0% of (0.50 × col. 32); RF to SW @100% of (0.50 × col. 32)

(iv) No RF is considered from water use for power, ecology, navigation and other use according to the NCIWRDP[1].

Total RF to GW (col. 34) = (col. 25 × 0.15 + col. 26 × 0.24) × 0.90 + {(col. 19 + col. 22) × 0.5} × 0.15 + (col. 32 × 0.5) × 0.0
Total RF to SW (col. 35) = (col. 25 × 0.15 + col. 26 × 0.24) × 0.10 + {(col. 19 + col 22) × 0.5} × 0.85 + (col. 32 × 0.5) × 1.0

scope for additional groundwater development of the order of 70%. However, we have found that the groundwater was already overexploited by 1997 based on the analysis of the data of the NCIWRDP[1].

The groundwater withdrawals were estimated as 230 BCM in 1997 by the NCIWRDP[1]. As already discussed, live storage capacity from completed projects was about 177 BCM in 1995 and it was assumed to be fully utilized by the year 1997. Considering reservoir losses at 20%, the water withdrawal from storages would have been about 142 BCM. Since the total water uses in 1997–98 were 593 BCM after correction for evaporation losses[1], the remaining 451 (593–142) BCM would have come from groundwater, either in the form of direct pumping or through river diversions. The replenishable groundwater resource due to natural recharge was 342 BCM and recharge to groundwater due to generated return flow in 1997–98 was estimated[1] as 143 BCM. Thus the total replenishable groundwater resource can be estimated as 485 BCM in 1997. The utilizable water resource from groundwater would be limited to 444 BCM (@ 0.915 of 485), while in fact 451 BCM of groundwater was used, after considering its interactions with surface water. This clearly shows overexploitation of groundwater even in 1997–98. This is in contrast to the CGWB assessment[9] that groundwater development was of the order of 32%; it suggested a huge scope for additional groundwater development. An urgent shift in the groundwater policy is called for to augment it through artificial recharge, rather than the existing policy of further development of groundwater. Otherwise, no water would be left for river diversions during the non-monsoon period.

Conclusion

This article is a review and analysis of various studies on utilizable water flows from surface and groundwater, and thereby the total utilizable water resources of India. The main findings can be summarized as follows.

(i) The utilizable water resources of India are overestimated in various studies ranging from 66% to 88%.

(ii) The total utilizable water flows of India are estimated as 668 BCM by us, as against 1110 BCM by the CWC[3], 1209–1255 BCM by the NCIWRDP[1] and 1122 BCM according to the National Water Policy of India[8].

(iii) We have also estimated the basin-wise utilizable water flows.

(iv) It is also shown that most of the basins are water-deficit even if low-demand scenario is considered by 2050. The total deficit of water in all the deficit basins has been calculated as 229 BCM.

(v) The scenario becomes worse if high water demands are considered for the analysis. Following similar calculations as done for the low-demand scenario, the total deficit increases to 396 BCM for the high-demand scenario.

(vi) It has also been shown that the groundwater had been overexploited even in 1997–98. This necessitates an urgent shift in the existing groundwater policy from further exploitation to augmentation.

The National Water Policy of India[8] has also adopted the overestimated figure of utilizable water resources, which needs to be corrected. It may be noted that the projected water demand of 897 BCM cannot be met even after full development of the water resources aggregating to about 668 BCM. The analysis yields that almost all basins will become water-deficit and this raises the big question upon the availability of water through inter-basin transfers.

Therefore, contrary to the views of the NCIWRDP[1], water scarcity is alarming and there is every reason to be worried. It may also be noted that this article only focuses on the quantity of utilizable water, assuming that all the water, including the return flows is of acceptable quality. The situation may be much worse in view of the deteriorating ground- and surface water quality. It calls for urgent action to review and implement water policies/plans in a time-bound manner in the light of the alarming water scarcity, before it becomes unmanageable, and to complete all possible storage works on priority basis. A shift in the approach of balancing the supply and demand is also required. This may call for an integrated approach of water supply and demand management. Water supplies must also be augmented with traditional approaches of water conservation locally, in addition to big projects.

1. Integrated water resources development: A plan for action, Report of the National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, New Delhi, 1999.
2. Kumar, R., Singh, R. D. and Sharma, K. D., Water resources of India. *Curr. Sci.*, 2005, **89**, 794–811.
3. Water resources of India, Publication No. 30/88, Central Water Commission, New Delhi, 1988.
4. Reassessment of water resources potential of India, Central Water Commission, New Delhi, 1993.
5. Report of the Irrigation Commission 1972, Irrigation Commission, Ministry of Irrigation and Power, New Delhi, 1972.
6. Rao, K. L., *India's Water Wealth*, Orient Longman Ltd, New Delhi, 1975.
7. Report of the National Commission on Agriculture 1976, National Commission on Agriculture, Ministry of Agriculture, New Delhi, 1976.
8. National water policy, Ministry of Water Resources, Government of India, New Delhi, 2002.
9. Ground water resources of India, Central Ground Water Board, Ministry of Water Resources, New Delhi, 1995.
10. Storage in river basin of India, Central Water Commission, Ministry of Water Resources, New Delhi, 1997.

Received 23 February 2007; revised accepted 22 August 2007