Water for India in 2050: first-order assessment of available options

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Water resources of India are examined in the context of the growing population and the national ambition to become and be seen as a developed nation. The motivation was provided by the continuing debate on the proposed project for interlinking of rivers by National Water Development Agency.

The population of India is expected to stabilize around 1640 million by the year 2050. As a result, gross per capita water availability will decline from ~ 1820 m^3/yr in 2001 to as low as ~ 1140 m^3/yr in 2050. Total water requirement of the country for various activities around the year 2050 has been assessed to 1450 km^3/yr. This is significantly more than the current estimate of utilizable water resource potential (1122 km^3/yr) through conventional development strategies. Therefore, when compared with the availability of ~ 500 km^3/yr at present, the water availability around 2050 needs to be almost trebled. Various options have been considered in quantitative terms, as possible sources to augment the anticipated deficit.

It is argued that due to considerations of gestation period and capital requirements, rainwater harvesting and water-conservation measures must receive the highest priority followed by renovation and recycling to be followed by intra- and then inter-basin transfers in the last phase. But, investigations and planning processes for all options must begin immediately.

WITH rapid population growth and rising expectation for a better life, the natural resources of our earth face increasing pressure. It is paramount that basic resources for human survival, viz. air, land and water must be properly managed. The quantity and quality of these resources are critical to ensure adequate food supplies, public health and transportation. In particular, the management of water resources has profound impact on society with regard to quality of life.

Water-management decisions can have environmental, physical, social and economic impacts that are widespread and pervasive. It is, therefore, necessary to have most relevant information for arriving at rational decisions that will result in the maximum amount of benefit to most people. Accurate and reliable information on the water resource system can, therefore, be a vital aid to strategic management of the resource. To appreciate this, an overview of the emerging water-resource scenario in India is presented in the following.

Emerging scenario – water resources of India

A gross annual assessment of available water resources of India[1] is given in Table 1. The Central Water Commission worked out the estimated utilizable surface water (EUSW) in each river basin. This is the quantum utilizable through conventional run-of-the-river schemes and storage reservoirs and among other constraints depends on availability of suitable sites for construction of dams and diversion structures. Total utilizable surface flow in all river basins of the country[2] was thus estimated ~ 690 km^3/yr. Further, a bare minimum live storage of 385 km^3 was estimated as needed to balance seasonal flows to achieve ~ 690 km^3/yr EUSW for irrigation of 76 mha. Sedimentation in reservoirs reduces utilizable resource.

Replenishable groundwater (RGW) resource was estimated by the working groups (constituted in 1994–95) based on a large volume of hydro-geological and related data generated by Central Ground Water Board (CGWB) and the State groundwater organizations and the existing knowledge of groundwater regime[1], as ~ 432 km^3. The estimated RGW is the sum of natural recharge from rainfall (342 km^3) and potential due to recharge augmentation from canal irrigation system (90 km^3).

Water requirement is a derived quantity. The key determining elements are the population and the desired quality of life. The latter depends on a large number of parameters

Table 1. National water resources of India at a glance

Resource	Quantity	Precipitation (%)
Annual precipitation (including snowfall)	4000 km^3	100
Evaporation + groundwater	2131 km^3	53.3
Average annual potential flow in rivers	1869 km^3	46.7
Per capita water availability (1997)	1967 m^3	–
Estimated utilizable water resources	1122 km^3	28.1
Surface water (EUSW)	690 km^3	17.3
Replenishable groundwater (RGW)	432 km^3*	10.8

1 km^3 = 10^9 m^3 = 1 billion cubic metre (BCM) = 0.10 million ha m.
*Natural recharge from rainfall (~ 342.4 km^3) + potential due to augmentation from canal irrigation system (~ 89.5 km^3).
Source: Ministry of Water Resources (MOWR)[1].

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such as food availability and security, industrial production, urbanization, water quality, ecology and environment, etc. Table 2 summarizes the various estimates on the population of India.

Using available demographic scenarios, the Ministry of Water Resources (MOWR)[1] decided to follow the higher (H) and lower (L) limits of India's population in the year 2050 corresponding to those estimated by Visaria and Visaria[3] and the UN[4] (low variant) respectively, i.e. 1581 and 1346 million. The Task Force on Interlinking of Rivers (TF–ILR)[5] has, however, projected the population of India in 2050 as 1640 million corresponding to the UN[4] (middle variant). In this discussion, the lower estimate (L) is taken as 1346 million with water requirement of 973 km^3/yr and the higher estimate (H) as 1640 million with water requirement of 1450 km^3/yr though, higher estimates (1700 million[6]; 1800 million[7]) have also been indicated by some. The gross per capita availability in 2050 is obtained by dividing the average annual potential river flow (~ 1869 km^3) by the higher and lower population estimates as 1140 and 1389 m^3 respectively. And, for a population estimate of 1800 million[6] in 2050, the gross water availability will decline to as low as ~ 1040 m^3. Viewed in the international perspective of '< 1700 m^3/person/yr as water-stressed' and '< 1000 m^3/person/yr as water scarce', India is water-stressed today and is likely to be water-scarce by 2050. Already, many parts of the country are water-scarce. For example, in Gujarat, the average per capita availability of water was already as low as 1079 m^3/yr – only 414 m^3/yr in north Gujarat – with utilization ~ 407 m^3/yr in the year 2001 (Gupta and Deshpande[8]; Figure 1). North Gujarat is also a region where extensive groundwater mining has been going on now for more than three decades, resulting in decline of water table/piezometric surface at a rate of ~ 3 m/yr. The new tube-wells tap water from strata as deep as 350–400 m.

Clearly, the emerging scenario in the country is alarming. This is also seen from Figure 1, where projected sector-wise water requirements up to 2050 for high (H) population projection, is compared with 1998 requirements. It is seen that the anticipated requirement for population projections (H = 1450 km^3/yr) will be significantly higher than the estimate of utilizable water resource of 1122 km^3/yr (surface water (SW) = 690; ground water (GW) = 432). Thus, to meet the shortfall, it is necessary to harness additional 475–950 km^3/yr for L and H population estimates over the present availability of ~ 500 km^3/yr.

Several strategies are possible, with each strategy having specific, though widespread and pervasive environmental, physical, social and economic impacts. Therefore, acquiring quantified knowledge about the spatial and temporal distribution of the different components of the local, regional and national hydrological cycle is vital to plan and develop water resources of the country at different scales at the least cost to ecology and environment, social fabric and economy over the next half a century or so.

In the following, a preliminary first order assessment of potential of additional water (above the 1998 figures) from (i) rainwater harvesting and artificial groundwater recharge, and (ii) reuse and recycle of wastewater is made. This is to examine if either of these strategies, singly or together, can provide the required quantity of water in the target year of 2050. The motivation was provided by the continuing debate[7,9–14] on the proposed project for interlinking of rivers by NWDA[15]. The present assessment is based on existing data of the available water resource, geo-hydrology, population projection and sector-wise water requirements in major basins of the country.

Basin-wise water resource potential

For the purpose of this assessment, the country is divided in 20 river basins as indicated in Figure 2. Basin-wise availability of water in the country is given in Table 3, taken from MOWR[1]. It is seen that both in terms of available surface water (ASW) and average monsoon run-off (AMR), Ganga and Brahmaputra are the two largest basins,

Table 2. Population projections by different scholars and agencies

	All-India population in year (in million)				
Reference	2000	2010	2020	2025	2050
Natrajan[19]	1020.5	1183.1	1301.0		
UN[4]					
A: Low variant	1013.0	1156.6	1249.7	1283.3	1345.9
B: Middle variant	1022.0	1189.0	1327.1	1392.0	1640.0
C: High variant	1030.5	1221.7	1406.1	1501.5	1980.0
Registrar General of India[20]	997.0	1162.0			
Visaria and Visaria[3]	995.0	1146.0		1333.0	1581.0

Source: MOWR[1]
The population of India according to 2001 census was 1027 million.

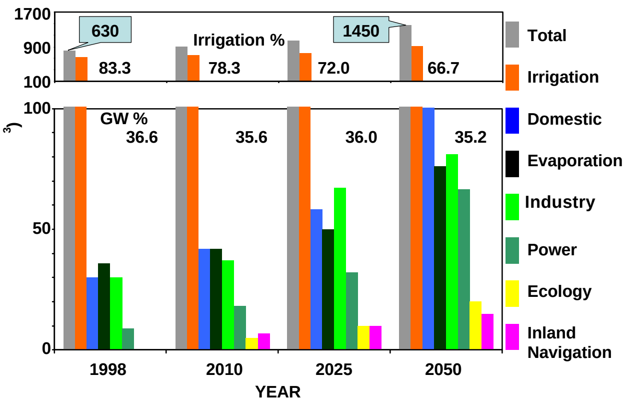


Figure 1. Anticipated water requirement for various sectors. The proportion of water used for irrigation is expected to decline as the requirement of all other sectors increases. Also, the proportion of groundwater is expected to decrease marginally. The total water requirement is, however, expected to increase by ~ 120%.

followed by Godavari, Krishna, Indus and Mahanadi. Because of geographic and topographic constraints, the EUSW in Brahmaputra is considerably low. The Ganga basin has by far the largest amount of EUSW (~ 250 km^3/yr). Because of the large surface area and the alluvial nature of the aquifers, the Ganga basin also has by far the largest (~ 170 km^3/yr) replenishable groundwater (RGW) resource. This is the amount of groundwater naturally replenished every year and stored within the zone of water-table fluctuations. The static fresh groundwater (SGW) resource is considered as exploitable groundwater available in aquifer zones below the zone of water-table fluctuation. The Ganga basin also has the largest SGW potential (~ 7830 km^3/ yr) followed by the Indus (~ 1340 km^3/yr) and the Brahmaputra basins (~ 1020 km^3/yr). It may also be noted that a part of the SGW reserve is already being exploited in some parts of the country, as for example in North Gujarat[7].

If the data given in Table 3 are examined together with those of commitments already made locally on surface water in the respective basins, it is seen (Figure 3) that only Brahmaputra and the west-flowing rivers of the Western Ghats have any significant quantity of monsoon run-off in excess of that already utilized and/or committed for use as part of ongoing or planned development projects. This must be kept in mind while devising any water-resource augmentation/development strategy.

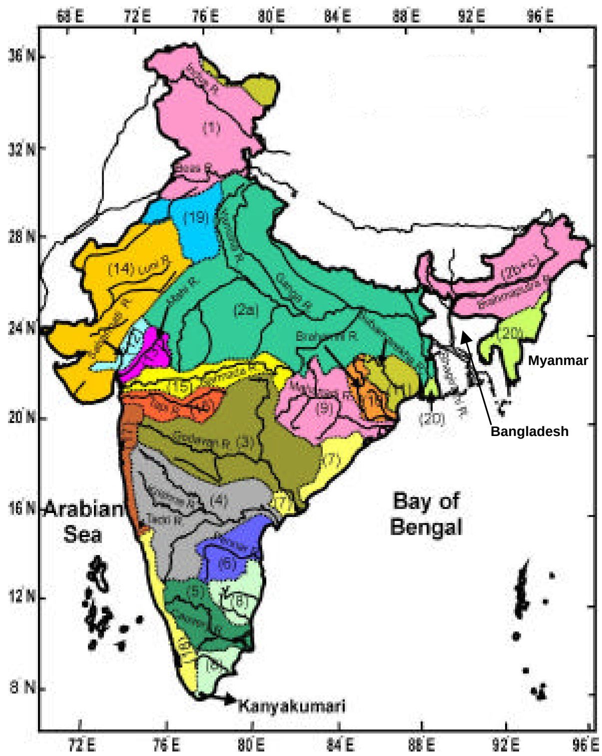
In general, the following elements seem to form part of a viable long-term water-resource development strategy:

(i) Achieve the full utilizable potential of ~ 1120 km^3/yr (SW = 690 km^3/yr; GW = 430 km^3/yr) to meet the anticipated demand (1182–1450 km^3/yr).
(ii) Convert part of static groundwater potential to dynamic potential by over-exploiting aquifers and artificially recharging part of monsoon run-off in excess of utilizable surface potential to these aquifers.
(iii) Increase irrigation leading to increase in dynamic storage of groundwater through exploitation/recharge of aquifers.
(iv) Reuse and recycle industrial and municipal wastewater.
(v) Transfer from basins with surplus water to basins with deficit potential.
(vi) Import agricultural produce – virtual water.

In the following, the potential due to elements (ii)–(v) listed above is examined using simple conceptual models.

Achievable artificial groundwater recharge model

The potential for rooftop rainwater harvesting, based on estimates of rainfall in different parts of the country and the available area of rooftops, has been estimated by the WMF[16] to be ~ 1 km^3/yr. Whereas, this water can be critical for drinking requirements in drought-prone areas, for large-scale planning its magnitude is too small and within the range of errors of estimation. Therefore, it is not considered any further.



1	Indus
2a	Ganga
2 (b+c)	Brahmaputra + Meghna
3	Godavari
4	Krishna
5	Cauvery
6	Pennar
7	East flowing: between Mahanadi and Pennar
8	East flowing: between Pennar and Kanyakumari
9	Mahanadi
10	Brahmani-Baitarni
11	Subernarekha
12	Sabarmati
13	Mahi
14	West flowing: Kachchh, Saurashtra and Luni
15	Narmada
16	Tapi
17	West flowing: Tapi to Tadri
18	West flowing: Tadri to Kanyakumari
19	Inland drainage in Rajasthan
20	Minor rivers draining into Bangladesh and Myanmar

Figure 2. Major drainage basins of India.

All other surface-water development and storage works essentially can be classified as run-off harvesting. But conventionally, run-off harvesting is understood as a component of rainwater harvesting through the traditional small structures. The availability of surplus water for run-off harvesting is huge, but is essentially restricted to the rainy season which lasts for only 3–4 months. Considering the rainfall pattern and the number of rainy days which vary

Table 3. Basin wise water in India (km^3/yr)

No.	Basin	ASW	AMR	EUSW	RGW	SGW
1	Indus	73.3	58.6	46.0	26.5	1338.2
2a	Ganga	525.0	401.3	250.0	171.6	7834.1
2(b + c)	Brahmaputra + Meghna	585.7	477.5	24.0	35.1	1018.5
3	Godavari	111.4	107.1	76.3	40.6	59.4
4	Krishna	78.1	61.0	58.0	26.4	36.0
5	Cauvery	21.6	18.9	19.0	12.3	42.4
6	Pennar	6.7	6.2	6.7	4.9	11.1
7	EF: Btwn Mahanadi and Pennar	22.5	15.3	13.1	18.8	41.3
8	EF: Btwn Pennar and K'kumari	16.5	16.0	16.5	18.2	66.0
9	Mahanadi	66.9	60.2	50.0	16.5	119.7
10	Brahmani–Baitarni	33.0	32.6	18.3	4.1	43.4
11	Subarnarekha	12.8	9.7	6.8	1.8	10.8
12	Sabarmati	3.8	3.4	1.9	3.2	28.2
13	Mahi	11.0	10.7	3.1	4.0	12.6
14	WF: Kachchh, S'tra and Luni	15.1	13.6	15.0	11.2	113.2
15	Narmada	46.0	36.9	27.5	10.8	18.4
16	Tapi	16.9	16.2	15.0	8.3	7.5
17	WF: Tapi to Tadri	87.4	80.3	11.9	17.7	11.2
18	WF: Tadri to K'kumari	113.5	97.8	24.3		
19	Inland drainage; Rajasthan	–	–	–	–	–
20	MR: B'desh and Myanmar	31.0	24.8	–	–	–
	Total	1878.3	1547.8	683.4	431.9	10,812.0

ASW, Available surface water; AMR, Average monsoon run-off; EUSW, Estimated utilizable surface water; RGW, Replenishable groundwater, including augmentation from canal irrigation; SGW, Static reserve of groundwater; EF, East-flowing; WF, West-flowing; Btwn, Between; MR, Minor rivers; K'kumari, Kanyakumari; S'tra, Saurashtra; B'desh, Bangladesh. Source: MOWR[1].

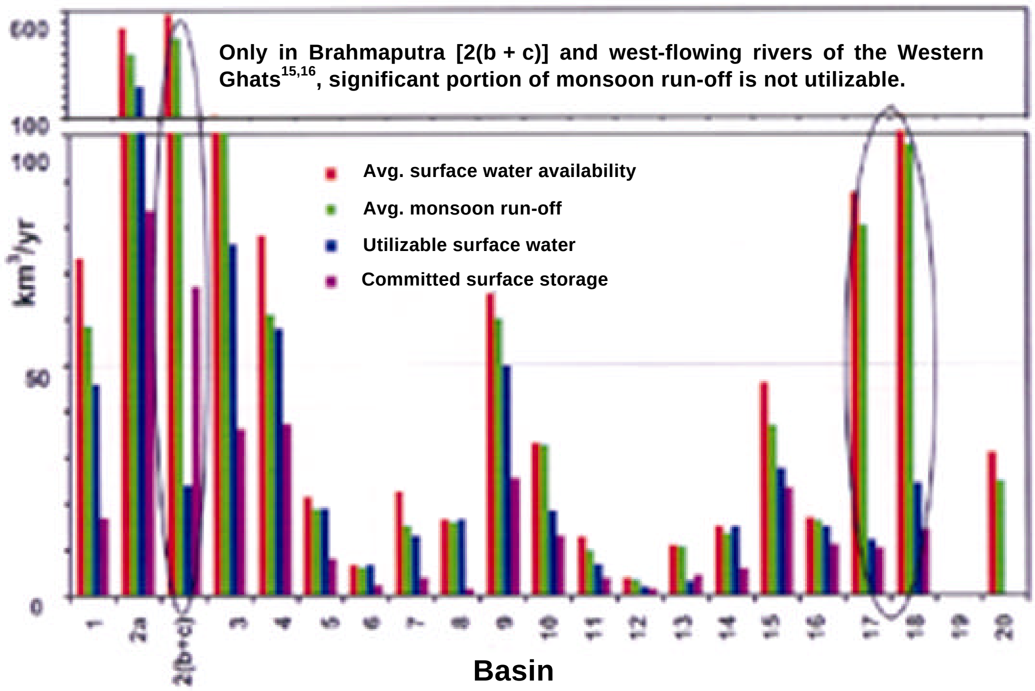


Figure 3. Water resource distribution in different drainage basins of the country. Basin codes are as given in Figure 2 and Table 3.

from 10 to 50, it is difficult to harvest large amounts of rainwater and store the same for later use through the traditional small structures. But, there is a large subsurface reservoir space available in aquifers for artificial groundwater recharge, particularly where large-scale exploitation of groundwater has led to the rapidly declining water table, as for example, in North Gujarat[7]. However, average monsoon run-off (AMR) is not uniform in all the basins, resulting in surplus and deficient monsoon run-off *vis-à-vis* subsurface storage potential (SSSP). In this study, only AMR in excess of EUSW is assumed available for artificial groundwater recharge. The EUSW is presumed to be best utilized directly for various applications. Further, though arbitrarily, it is also presumed that only 75% of the excess AMR can at most be recharged. This may actually be an overestimate, in view of the fact that in most parts of the country, monsoon run-off is generated only during heavy rainfall events and since effective groundwater recharge is a relatively slow process, there will be some run-off that will remain technologically un-rechargeable. This factor is also intended to take care of diversion to natural groundwater recharge (10–15%) and loss due to evaporation during surface storage for groundwater recharge operations. Therefore, potential artificial groundwater recharge or storage (PAGWR) = 0.75*(AMR–EUSW). The actual artificial groundwater recharge/storage (AAGWR) then equals SSSP when PAGWR $\geq$ SSSP, and equals PAGWR when PAGWR < SSSP. The SSSP of each river basin has been estimated by CGWB[17] based on geohydrological characteristics and fluctuations of the water table over the years in each basin, as shown in Figure 4 (*x*). Basin-wise calculations of distribution of AAGWR are also shown in Figure 4 (*y*). (In Figure 4, *z* is PAGWR–SSSP). The distribution of *z* (Figure 4) reveals that enough surplus monsoon run-off, in excess of utilizable surface water, is not available to fully utilize the SSSP of aquifers in most basins in the country. The basins of Brahmaputra, Godavari, Brahmani–Baitarni and the west flowing rivers on the Western Ghats cannot accommodate all the available surplus monsoon water in aquifer storage. Based on this model, AAGWR for India as whole is estimated to be 167 km^3/yr.

Because of technical constraints and groundwater flow dynamics such as filling-up of the exploited static groundwater (SGW) during periods of drought and slow drainage during the lean season to streams, it is once again arbitrarily presumed that only 75% of AAGWR can be retrieved. As a result, retrievable artificial groundwater recharge (RAGWR) $\approx$ 0.75*AAGWR $\approx$ 125 km^3/yr.

At this point, it is important to note that large-scale groundwater recharge on such a massive scale as envisaged in the foregoing, has not been resorted to anywhere in the world. Within India, farmers in Saurashtra region have successfully resorted to perhaps the largest groundwater recharge experiment during the last few years. But estimates, in terms of quantity are not available. Therefore, the 75% excess AMR as AAGWR may be an upper limit. However, in the following it will be seen that an error of ± 20% in this will not affect the results.

Irrigation return-flow model

In addition to artificial groundwater recharge, additional water is also available due to return flow (RF) of irrigation water in the form of surface discharges and infiltration in the groundwater sources. Only about 10% of RF from irrigation is expected to contribute to the surface water sources and the balance ~ 90% to groundwater sources[1]. It is a moot point whether this additional water should be treated in excess of the AAGWR. But since, as noted above, SSSP is not fully utilized in most river basins in the country, it appears reasonable to treat this as additional available water. The RF of irrigation water to ground water and surface-water sources depends on imbalance, i.e. difference between gross amount of water available and net irrigation requirement of water[1]. However, overall irrigation efficiency can also be expected to increase, leading to decrease in imbalance. MOWR[1] estimated the RF from surface- and groundwater irrigation depending on estimates of overall irrigation efficiency (Table 4).

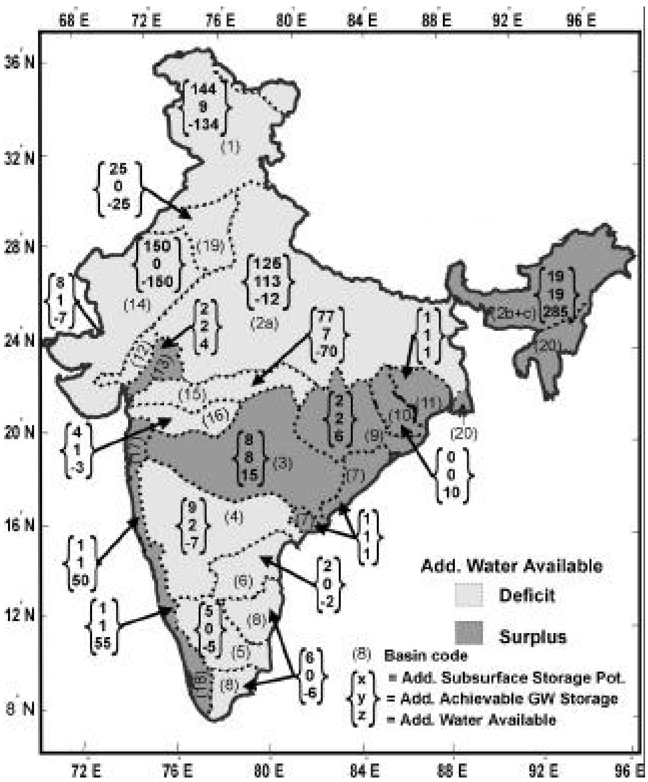


Figure 4. Additional (over 1998) achievable groundwater recharge in different basins of India (*y*). The SSSP (= *x*) of each river basin has been estimated based on geohydrological characteristics and the fluctuations of water table in each basin[17]. The surplus or deficit (–) of PAGWR over SSSP is indicated by *z*. Basin codes are as given in Figure 2 and Table 3. Units km^3/yr.

Based on this model, RF for 2050 has been estimated to be 123–223 km^3/yr for low and high population growth rates, giving 33–133 km^3/yr above the 1998 RF estimate[16] of 90 km^3/yr. It is possible that as the RF increases, there may be competition between this and the AAGWR, leading to waterlogging. But for the present, we assume that this situation can be avoided using the canal and groundwater conjunctively.

Recyclable wastewater model

Recycling is defined as the internal use of wastewater by the original user prior to discharge to a treatment system or other points of disposal. The term 'reuse' applies to wastewaters that are discharged from municipalities, industries and irrigation, and then withdrawn by users other than the dischargers. After treatment, reclaimed waters are generally used for irrigation, as cooling water, algal cultivation and pisciculture, apart from other industrial applications. For the purpose of this assessment, the following thumb rules have been applied:

- Municipal wastewater generation is about 75% of the supply. Only a part of this can be recycled.
- Industrial applications such as thermal power plants can have higher (~ 98%) recyclables, but other industries generally have less recyclable water[18].
- But since the projected industrial requirement (~ 193 km^3/yr) for 2050 is more than the domestic requirement (102 km^3/yr) that includes drinking and bovine needs, the overall recyclable water may be ~ 60% of the supply.
- At 60% of the supply, estimated recyclable water is between 103 and 177 km^3/yr for low and high population projections respectively.

Taking model estimate of recyclable wastewater, with those of EUSW, RGW, RAGWR and RF, the total water resource availability around the year 2050 for the low (L) and high (H) population estimates is given in Table 5. It is seen from Table 5 that the largest increase (~ 550 km^3/yr) in water supply can come from harnessing EUSW from conventional run-of-the-river schemes and the untapped GW potential, followed by RF under the assumption of full development of irrigation potential utilizing 1072 km^3/yr of water. It is also noticed that without contribution from RAGWR and recyclable wastewater, the projected water requirements cannot be met.

The estimates in Table 5 are for an average rainfall year throughout the country and do not take into account inter-annual fluctuations which, within the range of ± 20%, are considered as part of a 'normal' monsoon year. Fluctuations in spatial distribution even in a 'normal' year are also not considered. The range of these fluctuations is larger in low-rainfall regions than in high-rainfall regions. It is also apparent that the models used are simplistic and yield only a first-order estimate that can easily have an uncertainty of ~ 20%. Even so, it appears that during a 'normal' year, water conservation, recycling and reuse measures can significantly enhance the water availability that can take care of meteorological and other uncertainties, particularly to provide for a 'feel good' factor at the national level provided EUSW from conventional run-of-the-river schemes has been fully exploited to 690 km^3/yr. One may then be tempted to conclude that there is no need for inter-basin transfer of water. This assessment, however, ignores the regional imbalance in water availability and implicitly assumes that water in any given part of the country is available wherever required.

It was, however, shown in Figure 4 that only the Brahmaputra, Brahmani–Baitarni, Subarnarekha, Mahanadi, the east-flowing rivers between Mahanadi and Pennar, Godavari, Mahi and the west-flowing rivers of the Western Ghats have surplus monsoon water. The other river basins of the country have minor-to-large deficit of available monsoon run-off water.

The imbalance in water availability persists even on per capita basis and also on a regional scale. This is particularly

Table 4. Estimates of irrigation efficiency and irrigation return flow

Source ⟶	Surface water			Groundwater		
Year ⟶	2010	2025	2050	2010	2025	2050
Efficiency (%)	40	50	60	70	72	75
RF as% GIR*	36	30	24	18	17	15

*Gross irrigation requirement = water delivered from source.

Table 5. Water resource availability for 2050 (km^3)

Water available during 2001	Water required during 2050		Anticipated water deficit over 1998		Possible measures to meet the deficit: EUSW + GW in excess of 1998	Model recyclable wastewater		Model irrigation return flow		Model RAGWR	Water availability
Population model	L	H	L	H		L	H	L	H		H (L)
(1)	(2)	(3)	(4) = (2–1)	(5) =(3–1)	(6)	(7)	(8)	(9)	(10)	(11)	(12) = 1 + 6 + 8 + 10 + 11
~ 500	973	1450	473	950	SW 420† GW 202 550$	103#	177#	33†	133†	125	1485 (1311)

$After considering 17% decline in live SW storage capacity due to sedimentation.
†Assumed high application and operation efficiency.
#Ignored water quality issues.

seen in Gujarat, where water availability is highly skewed, with South and Central Gujarat having most of the water resources and North Gujarat with only about 400 m3/ person/yr availability, having already developed all its available water resource. It is a similar picture in the Cauvery basin, where interstate water disputes have become a routine affair. It is not possible to increase the availability of water in such areas without bringing water from other basins. This is true even after EUSW + RGW has been fully developed and measures for conservation, recycling and reuse of water have been put in place. The proposal for the interlinking of the rivers should, therefore, be viewed in this context.

Inter-basin water transfer

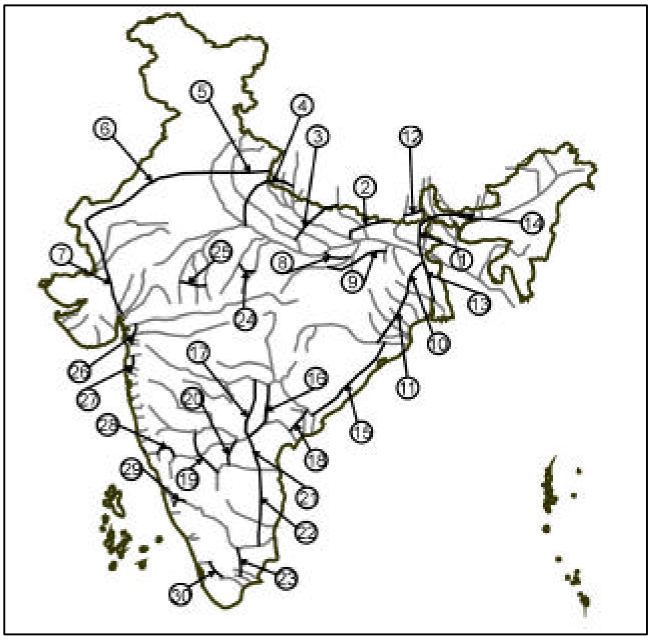
NWDA[15] has formulated the latest version of the inter-basin transfer project. The plan has divided the project in the two broad components, (i) the Himalayan component with 14 river links and (ii) the peninsular component with 16 river links (Figure 5). It is planned to transfer ~ 141 km^3/yr through the peninsular links for redistribution within peninsular India, and ~ 33 km^3/yr through the Himalayan links, essentially for redistribution in the Ganga basin and to western India. Although huge amount of surplus water is available in the Brahmaputra and Brahmani–Baitarni basins, since major parts of these rivers flow at an elevation lower than the Ganga basin, only a small volume of water can be transferred from the Brahmaputra basin. It is worth noticing that the major volume of water proposed to be transferred through the project on interlinking of rivers is in the peninsular component, where major water-deficits exist and/or are feared. Other important proposed links are Sarda to Yamuna, Yamuna to Rajasthan and Rajasthan to Sabarmati, which will bring water to the parched land of western India. It is thus clear that a major objective of the proposed inter-basin transfer of water is to meet requirements of highly water-deficit areas, where no other source is possible. The total volume of water (~ 174 km^3/yr) proposed to be transferred through the two components is less than the combined water that can be made available (~ 300 km^3/yr) through water conservation, groundwater recharge and recycling efforts, but is critical for the areas where it is proposed to be transferred. These areas are already facing water-scarcity conditions. If the volume of water to be transferred through the proposed links is added to Table 5, we get a healthy picture of ~ 1660 km^3/yr of developed water resource for the country that can take care of any exigencies.

Virtual water

A large amount of water is consumed for agricultural production and will continue to be so (Figure 1). Therefore, import of food virtually amounts to conserving/having water. This is commonly known as virtual water. However, given the large size of the Indian population, the role of agriculture both directly and indirectly in the Indian economy and the desire to become and be seen as a developed nation, food security for the country is something on which no Indian may be willing to compromise. The begging-bowl image of the sixties cannot be accepted. Therefore, a planned import of foodgrains to feed the burgeoning population of the country in the coming years is not considered any further.

Summary and discussion

As a result of the growing population, parts of India are already facing water-scarcity conditions. By the year 2050, when the population is expected to stabilize, India as a whole will be on the verge of becoming water-scarce. Around the year 2050, water requirement has been assessed



Himalayan component

1. Brahmaputra–Ganga (MSTG)
2. Kosi–Ghagra
3. Gandak–Ganga
4. Ghagra–Yamuna
5. Sarda–Yamuna
6. Yamuna–Rajasthan
7. Rajasthan–Sabarmati
8. Chunar–Sone Barrage
9. Sone Dam–Southern tributary of Ganga
10. Ganga–Damodar–Subernarekha
11. Subernarekha–Mahanadi
12. Kosi–Mechi
13. Farakka–Sunderbans
14. Brahmaputra–Ganga (JTF)
    MSTG: Manas–Sankosh–Tista–Ganga
    JTF: Jogigopa–Tista–Farakka
    (Alternative to MSTG)

Peninsular component

15. Mahanadi (Mani Bhadra)–Godavari (Dowlaiswram)
16. Godavari (Inchampalli Low Dam)–Krishna (Nagarjunasagar Tail Pond)
17. Godavari (Inchampalli)–Krishna (Nagarjunasagar)
18. Godavari (Polavaram)–Krishna (Vijaywada)
19. Krishna (Almatti)–Pennar
20. Krishna (Srisailam)–Pennar
21. Krishna (Nagarjunasagar)–Pennar (Somasila)
22. Pennar (Somasila)–Cauvery (Grand Anicut)
23. Cauvery (Kattalai)–Vaigai–Gundar
24. Ken–Betwa
25. Parvati–Kalisindh–Chambal
26. Par–Tapi–Narmada
27. Damanganga–Pinjal
28. Bedti–Varda
29. Netravati–Hemavati
30. Pamba–Achankovil–Vaippar

Figure 5. Schematic of the link canals as proposed by NWDA for inter-basin transfer of water.

between 970 and 1450 km^3/yr for various activities. This is precariously close to the current estimate of utilizable water resource potential (1122 km^3/yr) through conventional development strategies. Taking cognizance of the rainfall variability, the errors inherent in such estimates, slippages in development works, etc., it is desirable that long term planning be undertaken to develop ~ 25% more potential than the anticipated requirement. This is important as, according to some projections[6], the population of India may be as high as 1800 million in 2050. When compared with the present availability of ~ 500 km^3/yr, the water availability around 2050 needs to be almost trebled. Various options have been considered in quantitative terms as possible sources to augment the anticipated deficit. These include: (i) conservation of water through rainwater harvesting and groundwater recharge, (ii) recycling and reuse of municipal and industrial wastewater, (iii) utilizing increased return flow from irrigation, (iv) inter-basin transfer and (v) virtual water.

To meet the growing requirements of water for various applications and to be counted as a developed nation, it is imperative not only to develop the new water sources but to conserve, recycle and reuse water wherever possible. It has been shown that conservation of water through rainwater harvesting and artificial groundwater recharge can generate about 125 km^3/yr of additional water. Similarly, recycling of municipal and industrial wastewater can regenerate another ~ 177 km^3/yr water. Both these measures provide water at local scale, where people live and engage in productive activities. However, it is only the former, namely rainwater harvesting and artificial groundwater recharge, where people and communities can directly participate due to the low level of technologies involved. The gestation period for such projects can be a few months to a few years and because of the distributed nature of this activity, it is only through the involvement of people and communities that sustainable works can be carried out. Whereas in the latter case, namely recycling and reuse of wastewater, local governments such as municipalities and industries are required to carry out the development work. The gestation period for such activities can be a couple of years as the required technology becomes more advanced and the capital, intensive. At the next level, there is still untapped potential of almost 550 km^3/yr comprising groundwater and conventional run-of-the-river schemes. Further, inter-basin transfer of water as proposed by NWDA[15] can generate another ~ 174 km^3/yr of water. But due to the complex political, technological and financial requirements both intra- and inter-basin projects can only be undertaken by the State and national government agencies. The gestation period in these projects can be a couple of years to decades.

In the foregoing analysis, the population of India has been assumed to stabilize around the year 2050 at 1640 million. If the population cannot be contained as has been seen in the past, the requirement of water may go up. It was also shown that for a lower population estimate of 1350 million, the water requirement is only 973 km^3/yr, well within the estimated utilizable water resource of 1122 km^3/yr (SW 690 + GW 432). Therefore, it is necessary that a significant national effort be devoted to limit the population growth. At the same time, it is also necessary that projections of population and demand of water be reviewed at regular intervals so that corrective actions can be taken in time.

It is, however, clear that in the short term the maximum amount of water can be generated locally through rainwater harvesting and artificial groundwater recharge projects, wherein people and communities not only participate but are also the direct beneficiaries. Another area of immediate emphasis has to be the recycling and reuse of water, because it not only generates water for subsequent use but also prevents pollution and ecological hazards. The impact of conservation, recycle and reuse is largely local but widespread and is the only way to drought-proof the country. The planning for both intra- and inter-basin transfer of water has to clearly begin now, because of the long gestation period involved. It is also important to note that only through projects of this nature can we generate the power required for groundwater pumping, provide water for inland navigation and meet ecological requirements. Every developed society has to provide for such requirements.

Therefore, it is clear that India as a nation has to now initiate action on all fronts for developing its water resources. The priority of action, however, must be for rainwater harvesting and groundwater recharge, followed by renovation and reuse of wastewater and then inter-basin transfers. This is the larger national picture, though adjustments at local and regional levels may have to be made.

1. MOWR, Integrated water resource development – a plan for action. Report of the National Commission for Integrated Water Resources Development Plan, Ministry of Water Resources, Govt. of India, 1999, vol. 1, p. 515.
2. CWC, Pricing of water in public systems in India. Report of the Central Water Commission, Govt. of India, 1993.
3. Visaria, L. and Visaria, P., *Prospective Population Growth and Policy Options for India, 1991–2001*. The Population Council, New York, 1996.
4. UN, *World Urbanisation Prospects. The 1994 Revisions*, United Nations, New York, 1995.
5. TF–ILR. Interbasin water transfer proposals. Task Force on Interlinking of Rivers, Ministry of Water Resources, Govt. of India, New Delhi, 2003, p. 27.
6. Kasturirangan, K., A space agenda for water: challenges and perspectives. National Symposium on Remote Sensing for Natural Resources with Special Emphasis on Water Management and Annual Convention of Indian Society of Remote Sensing, 4 December 1996.
7. Kirloskar, S. C., Monsoon magic: creating rivers of hope in India. *The Times of India*, Ahmedabad, 20 November 2003.

8. Gupta, S. K. and Deshpande, R. D., Isotopes in water resource management. Proceedings of International Conference on Water and Environment, Bhopal, India, 15–18 December 2003.
9. Radhakrishna, B. P., Linking of major rivers of India – bane or boon? *Curr. Sci.*, 2003, **84**, 1390–1394.
10. Gurjar, B. R., Interlinking of rivers: a climatic viewpoint. *Curr. Sci.*, 2003, **84**, 1381–1382.
11. Aiyar, S., Changing the course. *India Today*, 20 January 2003, pp. 28–32.
12. Vaidyanathan, A., Interlinking of rivers I and II, http://www.hinduonnet.com/thehindu/2003/03/26/stories/2003032601081000.html.interlinkingofrivers, 2003.
13. Prabhu, S., Interlinking of rivers – taskforce to look into all aspects, 2003, http://www.thehindubusinessline.com/2003/03/stories/2003033100521300. htm.
14. Shiva, V. and Jalees, K., Sujalam: living waters, the impact of river linking project. Navdanya, New Delhi, 2003, p. 106.
15. NWDA, A presentation CD on interlinking of water. National Water Development Agency, Ministry of Water Resources, GOI, 2003.
16. WMF, *Theme Paper on Inter-basin Transfer of Water in India – Prospects and Problems*, Water Management Forum, The Institution of Engineers (India), New Delhi, 2003, p. 30.
17. CGWB, National perspective plan for recharge to groundwater by utilizing surplus monsoon runoff. Unpublished report, Central Ground Water Board, Ministry of Water Resources, GOI, 1996.
18. Tyagi, P., Sengupta, M. and Chakrabarti, S. P., Making the best use of waste-water. Proceedings of the National Seminar on New Perspectives in Water Management, 1994.
19. Natrajan, K. S., Population projections for India. Proceedings of the 17th Conference of the Indian Association for the Study of the Population, Annamalai University, Tamil Nadu. 1993.
20. Registrar General of India. Population projections of India and states 1996–2016. Ministry of Home Affiairs, GOI, New Delhi, 1996.

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