Water Security in India: Three Scenarios for 2040

M. Dinesh Kumar

1 Introduction

Any debate on future water challenges of a country should be based on development of future scenarios of water using alternative evolution of major factors driving water demand and supply situation. The key factors that drive changes in water scenario are: economic growth, demographic changes, technological innovations, social changes, changes in environment and governance change (Gallopín & Rijsberman, 2000). Economic growth is necessary for poverty alleviation. Since Independence, India has made substantial progress on the economic front with the per capita net national product recording a compounded growth rate of 1.7%. This is evident from the decline in poverty rate from 45% in 1951 to around 28% in 2000 (Source: Dutt & Ravallion, 2002).

Contribution of agricultural production to this progress in GDP growth has been quite phenomenal, as its value in real terms grew 4.5 times during the 58-year period from 1954–55 to 2012–13 (Source: author's own analysis using Planning Commission data). Irrigation, which constitutes a major share of the total water consumption in competitive use sectors (Amarasinghe et al., 2004), has been the key to enhancing agriculture production and food security situation of the nation (Acharya, 2009), though its contribution was higher in the land rich, but naturally water-scarce regions. Providing safe water for drinking and sanitation are social goals. Water is also needed for industrial production purposes, pollution assimilation and a variety of environmental services (Kumar, 2010). India has also made substantive achievements in the provision of protected water supplies for drinking and domestic uses in both rural and urban areas.

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The social, economic and environmental value of water is being felt more strongly than ever before as demographic and socio-economic processes are putting enormous pressure on the limited freshwater reserves, more so in the water-scarce regions of western, north-western and southern parts of India. The average per capita freshwater availability in India, which stood at 5178 m^3 per annum in 1951, would decline to 1221 m^3 per annum by 2041 (CWC, 2017). But this does not capture the sharp regional variations. Many major river basins in India are already water stressed, and local scarcity and environmental problems are endemic in all basins (Amarasinghe et al., 2004; Kumar, 2010). In the arid western Rajasthan, the per capita renewable water availability is as low as 200 m^3 per annum, against high values for eastern Gangetic basin areas covering northern Bihar, eastern UP, Assam and West Bengal.

The approach to planning, development and management of water resources has been, by and large, centralized, sectoral and segmented (World Bank/GOI, 1998; Kumar, 2010). This approach, which is mainly intended to maximize the benefits of water to individual sectors, not only led to unsustainable development, but also led to several negative social, economic and environmental consequences. The government responds to the problems with increasing number of environmental legislations and regulations which are, by and large, ineffective (Kumar, 2010). The recent efforts have focused on engineering solutions such as setting up of large-scale wastewater treatment systems, and direct monitoring and control of pollution of rivers, and creating market demand for treated wastewater and environmental management services (Narain et al., 2018).

Fast-growing urban population, increase in per capita income and industrialization continue to raise the demand for water in the country, and the phenomenon of high growth in water demand is more pronounced in the water-scarce regions than in the water-rich regions Yet, technological and institutional interventions to manage the same are not forth-coming. While "business as usual scenario" is most unlikely to work in the context of forecasting future water demands due to alternative evolutions of the drivers of change in demand (Gallopín & Rijsberman, 2000), a clear and objective understanding of the water–nature–society–economy nexus is essential for framing rational, efficient and equitable water policies (Tortajada, 2001).

The estimates of future water demand presented in this article are based on the premise that the water demand in certain sectors like water supplies and food production would be driven by the long-term economic growth trends and demographic trends, respectively, whereas to allow the Indian economy to grow in various key subsectors, viz. industry and production of commercial crops at rates seen in the recent past, we need to enhance provision of water. While doing so, economic growth itself would demand change in technology, governance and environmental conditions. But such drivers were not considered while generating scenario of demand and supplies in the estimates available so far in the Indian context.

In future, there would be greater pressure to release water from large reservoirs for environmental needs. In order to defer investments for creating new storages, there would be greater pressure to reduce "losses" in irrigation systems and to improve the efficiency of irrigation water supplies (GOI, 2013).

As per latest estimates by the Associated Chambers of Commerce of India, India loses approximately INR 926 billion (US$ 14.33 billion) on account of post-harvest losses (PIB, 2016). A country-wide study measuring crop losses revealed that the losses during harvesting, post-harvest activities, handling and storage amount to 4.6–6% in the case of cereals, 6.4–8.4% in the case of pulses, 3.08–9.96% for oilseeds, 6.7–15.88% for fruits and 4.56–12.44% for vegetables (Jha et al., 2015). Hence, India is likely to witness greater investments for reducing food losses, which in turn would help reduce the demand for water in the agriculture sector indirectly. With land prices skyrocketing and opportunity cost of using land for low value crops increasing, there would be greater pressure to invest in research towards increasing the genetic yield potential of major cereal crops. The idea is that based on the picture emerging from the "business as usual scenario" with assumptions on the evolution of limited drivers, alternative governance mechanisms and policies could be thought about to affect changes in technologies, socio-economic system and the environment.

2 Development and Economic Growth in India Since Early 90s

Since economic liberalization India witnessed rapid economic growth, with the average annual growth in GDP fluctuating between a lowest of 3.88% and a highest of 9.57% during 1992–93 and 2016–17, a major departure from a long-term average annual growth rate of 3–3.5% (Basu & Maertens, 2007). The annual agricultural growth rates also got stabilized during this period. It fluctuated between −2.97% (1997–98) and 10.4% (1996–97), again a significant departure from the earlier periods during which the fluctuation in annual growth rates in the sector was much wider, i.e. between a lowest of −11.04% during 1965–66 to a highest of 15.64% during 1988–89 (Source: author's own estimates based on agricultural statistics). One major reason for this was the tremendous growth in irrigation sector during this period, and the gross irrigated area expanded consistently from 63.2 m. ha in 1990–91 to 95.77 m. ha during 2013–14, a major portion of which came from expansion in well irrigation throughout the country.

The food grain production in the country saw a commendable growth from 50.8 m. ton in 1950–51 to 275.1 m. ton in 2016–17. A lot of the growth in food grain production resulted from crop yield improvement, while some occurred due to area expansion.[1] Another important change in the farm sector is the increasing crop diversification, with larger area under high-value fruits, vegetables, spices and other cash crops (MoAFW, 2016; Rada, 2013). The average annual growth in agricultural GDP in Indian today is far higher than that of the past, crop diversification being the

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[1] The average yield of paddy, wheat and sugarcane in India has been growing at an annual rate of 1.85%, 2.51% and 1.02 per cent, respectively, during 1980 and 2012 (Alexandratos and Bruinsma, 2012).

major contributing factor (Rada, 2013). More importantly, there has been a consistent decline in variability in annual GDP growth rates in the sector (GoI, 2013: p. 3).

Such changes had effect on several sectors. At the time of its independence in 1947, India had: a literacy rate of 18%. The life expectancy at birth was 32 years. The annual population growth rate was 1.25%. Against this in 2005/6, India had a literacy rate of around 60%; life expectancy at birth of 63 years; an annual population growth rate of 1.5%; and an annual GDP growth rate of around 8.4% (Basu & Maertens, 2007). Though there is dispute over the rate of acceleration of poverty rate reduction in India, the poverty rates did drop significantly since economic liberalization (Dutt & Ravallion, 2002).

The improvements in social infrastructure would have added to this growth. As per 1991 census, nearly 62% of the population had access to drinking water supply and this went up to 86% in two decades (source: Census of India, 1991 and Census of India, 2011). The proportion went up to 89.9% in 2015–16 as per 4th National Family Health Survey (NFHS). As regards access to improved sanitation facilities, the figures went up from 29.1% as per 3rd NFHS of 2005–06 to 48.4% as per 4th NFHS of 2015–16 (MOS & PI, 2017), and these figures have improved drastically during the past three years as a result of concerted efforts from the central and state governments, and private sector initiatives. Improvements economic growth rates mean increased demand for water for key economic sectors especially industry and commercial uses, while improvements in social infrastructure such as provision of piped water supply and improved sanitation system would raise demand for water in the domestic sector (Grey & Sadoff, 2007).

3 The Future Water Requirements for Different Sectors in India

3.1 The Assumptions

1. Improved economic conditions will encourage people to have better sanitation facilities, which would mean increased water requirement. It is expected that by the year 2025 itself, all Indian households both in rural and urban areas will have access to piped water supply in the dwelling premises, and all households will have access to improved toilets. Better access to water supply and sanitation means greater level of water use.
2. As regards domestic water use, we have begun our analysis assuming that rural areas would use around 100 lpcd of water and urban areas required 200 lpcd of water in the year 2040. In the case of urban areas, the figure of 200 lpcd is quite realistic considering the hot and arid or the hot and humid climate in which most large cities of India are located. However, considering the Ministry

of Jal Shakti's recommendation of 135 lpcd of water for urban areas, we have also considered this norm for estimation of urban water demand of 2040.

3. The actual industrial production figures were obtained from the report of the National Commission on Integrated Water Resources Development titled "Integrated Water Resources Development A Plan for Action" (GOI, 1999). They were later on verified and corrected on the basis of the data provided in the 9th plan document (GOI undated: 661). The per unit water consumption figures—as taken from the Report of the National Commission on Integrated Water Resources Development (Annexure 5.7: page 455)—were based on information available from Central Pollution Control Board (CPCB) and the Industrial Association of the particular sector of industry. Using both the figures, the industrial water consumption during 1997 was estimated for all 17 sub-sectors.
4. National Sample Survey data shows that during the period from 1987–88 to 1999–2000, the per capita aggregate fine cereal consumption declined from 135.5 to 135.5 kg in the rural sector and 115.6–114.6 kg in the urban sector (NSSO, 2001). The weighted average for the whole country was 148 kg per capita per annum (405 gram per day). The data from the 68th round of National Sample survey shows that during the period from 2004–05 to 2011–12, the per capita consumption of fine cereals went down from 126.73 to 123 kg in rural areas and 108.84–102.97 kg in urban areas (NSSO, 2015). However, the per capita food grain availability steadily increased from 166 kg during 1981 to 177.9 kg during 2017 (Source: Dept. of Agriculture, Cooperation & Farmer Welfare, 2017). The per capita availability of pulses in the recent years is on an average of 41.6 g per day in 2012 (Source: Dept. of Agriculture, Cooperation & Farmer Welfare, 2017) per capita consumption stood at a mere 28 g per day in 2011–12 (NSSO, 2015). Increasing population will increase the requirements for food grains that include fine cereals such as wheat and rice, course cereals and pulses. We have assumed a per capita food grain requirement of 500 g per day, with the fine cereals such as wheat and rice contributing 80% (i.e. 400 gm/day or 146 kg/year).
5. Though with rising per capita income and urbanization, the direct consumption of cereals has been found to decline over time (Source: based on NSSO, 2001 & 2015), the real demand for cereals will not decline due to the consumption pattern shifting towards meat and eggs, which require food grains for animal and poultry feed.
6. The key assumptions for estimating agricultural water requirement are: [1] The requirement of rice and wheat in the food consumption basket would become equal by the year 2010 (as considered by Kumar (2010)) and would continue till 2040. [2] The contribution of rain-fed paddy to the total paddy production would be 40% and that of rain-fed wheat be 0.0% by 2040. [3] The percentage contribution of groundwater and surface water to production of irrigated rice is assumed to become 25% and 75%, respectively. [4] The yield levels of wheat and rice for canal and groundwater irrigated areas were assumed as 3.0 t/ha & 3.2 t/ha and 2.70 t/ha & 3.0 t/ha respectively, figures considered by Kumar (2010) for water demand projections for the year 2025. Though there is remarkable

variation in yield of both wheat and paddy across the country—with highest yields obtained in north-western region (Punjab) to the lowest figures in Bihar (Aggarwal et al., 2008) average figures are used here to capture the aggregate situation at the country level. The yield level for sugarcane was taken as 80 t/ha in 2025. The yield of wheat and sugarcane was projected to increase at a rate of 2% per annum till 2040 and that of rice was projected to increase at a rate of 2.5% per annum till 2040 [5]. The total water supply requirement for irrigating one hectare of wheat is taken as 0.48 hectare-metre (ha m) and 0.80 ha m for groundwater and canal irrigated areas for the year 2010 in the water demand projections carried out by Kumar (2010). For rice, values taken are 1.2 ha m and 1.8 ha m, respectively, for the base year, with conveyance efficiency values of 100% and 55%, respectively, for groundwater and surface water. For sugarcane, the value is 2.18 ha m. Here, the physical efficiency of surface irrigation (including the farm efficiency) was taken as 55% including the field efficiency for the entire time frame and that for groundwater irrigation was assumed as 100% [6]. It is expected that there would be major investments coming up in the coming years for improving the efficiency of public irrigation systems, resulting in improved conveyance efficiency. It is assumed that by the year 2040, the conveyance efficiency in surface irrigation systems would rise to 80%. Though this intervention would reduce the water supply requirement at source remarkably, it will not result in real water saving, as most of the water lost in conveyance under inefficient conveyance practices is actually recycled back through wells for irrigation and other uses in the canal command areas (Perry, 2007; Perry & Steduto, 2017). [7] Water requirement for producing oil seeds, vegetables and other crops was assumed to be 20 % of the water required for producing cereals and sugarcane and treated as constant over time.

7. The industrial water requirement in India for the year 2010 was estimated to be 23.955 BCM, the figures estimated by Kumar (2010) in the water demand projections for 2000–2025. Industrial water requirements for future years were estimated by taking an per capita annual industrial growth rate of 3.5% and a per capita industrial water requirement of 18.86 m^3 estimated for the year 2010 (i.e., 23.955 X 10^9/population of 2010). It was further assumed that in 2040, the water intensity of manufacturing would reduce to 67% of the 2010 levels.

3.2 Water Requirement Projections

The national-level aggregate water requirements are estimated for projected future demographic and socio-economic scenario for the year 2040. It is well acknowledged that India is highly heterogenous country with wide variation in the physical environment and socio-economic profile of the people across regions, both having the potential to influence the demand for water in key water use sectors. For instance, the country's climate varies from cold and humid (in some pockets in the north-east) to hot and humid to hot and arid (western Rajasthan, south-western Punjab and Kachchh). The socio-economic conditions also vary widely from highly urbanized regions with high level of industrialization in the western, north-western and southern parts of the country to very backward regions in the eastern parts. Both the above-mentioned attributes have enormous potential to influence the requirement of water in three key sectors.

As regards the influence of the physical environment on agriculture sector, it will be through its ability to alter crop yield and crop ET. For the same crop, water requirement for meeting evapotranspiration requirements would be very low in the cold and humid region and very high in the hot and arid region (Amarasinghe &Sharma, 2009), while it will be vice versa as far as yield is concerned. Finally, the demand for water to produce a kg of produce is decided by the water productivity that can be achieved in each region.

However, since the latter category of regions also have large amount of arable land, the aggregate demand for irrigation water would be much higher there, as most of the agricultural production will be from those regions (Amarasinghe et al., 2004). Water requirement for domestic and livestock uses also will be lowest in the cold and humid regions and highest in the hot and arid regions. As regards the influence of the second factor (i.e. socio-economic conditions), the per capita demand for water for domestic uses will be higher in the developed regions due to higher standard of living (with the adoption of improved sanitation systems, modern equipment for washing, etc.).

While estimating future water demands (supply requirement) in agriculture, the water productivity variations in crops due to climatic differences are reconciled with by taking average values of yield per unit of water applied, in the case of domestic use, such effects are not considered in view of the fact that its effect on the estimates of overall water demand will be insignificant.

As per the World Urbanization Prospectus of the United Nations Population Division, India's population is projected to grow to 1605 million people, with urban population accounting for 46% (744.38 million). The water requirement for various purposes such as drinking and domestic needs, livestock uses, industry and agricultural production are analysed separately. The basic assumptions involved in the analysis are: [1] population growth will increase the domestic water requirement; [2] population growth will also increase food grain requirement, meaning more area under irrigation and increased water requirements for irrigation; and [3] industrialization will increase the demand for water for production processes and indirect demand for pollution assimilation.

The domestic water demand will grow proportional to the population. The actual growth rate in domestic water demand would, however, depend on where the population actually grows, i.e. whether in the rural areas or urban areas, and how. The rise in domestic water demand induced by a growth in urban population would be higher than that created by the same growth in rural population, as the water requirement for the basic survival needs are higher in urban areas. Faster growth in urban population will impact demand for water positively. Also, per capita water demand will rise with increase in income levels. The available evidences indicate that water demand is highly elastic at low income and low water use levels and that elasticity for domestic water will decline gradually as income and water use rise (Rosegrant et al., 1999).

We have begun our analysis based on the assumption that rural areas required 70 lpcd of water and urban areas required 150 lpcd of water in the year 2010. This is expected to grow at a rate equal to the per capita income levels till the total water requirement reaches 150 lpcd and 200 lpcd, respectively for rural areas and urban areas. Thereafter, it is expected to stabilize due to several interventions for improving water efficiency. These estimates suggest that the domestic water requirement would grow to 15.52 M. ha m in 2040. Another scenario was, however, considered in which the per capita urban water demand was assumed as 135 lpcd, in line with the current thinking in the government policy circles. As per this assumption, the total domestic water demand for rural and urban areas for 2040 was estimated to be 12.97 MCM.

The water requirement for livestock was estimated by taking the average of the estimated total water consumption by different types of livestock in two river basins of India (Luni in Rajasthan and Mahanadi in Chattisgarh) (5.08 m^3 per capita per annum), worked out in per capita terms for the basin populations and estimated for the projected future population of India. The total livestock water demand was thus estimated to be 0.815 M ham (i.e. 1605 × 5.08/10000).

The projections of industrial water requirement for the future years were made on the basis of the following: [1] actual industrial production figures in 17 identified sub-sectors of industries for the year 1997; [2] water requirement for unit production of industrial outputs for each of the 17 sub-sectors (Source: GOI, 1999); [3] an assumed per capita industrial growth rate of 3% per annum till the year 2040; and [4] an increase in water use efficiency of manufacturing to the tune of 50%, i.e. reduction in water intensity of industrial production by 33%. The industrial water requirement estimated for 2010 by Kumar (2010) was 2.395 M ham, with a per capita requirement of 18.86 m^3 (Kumar, 2010: Fig. 1, Chap. 2) with an annual growth of 3% in per capita industrial output and a 33% reduction in water intensity of manufacturing, the

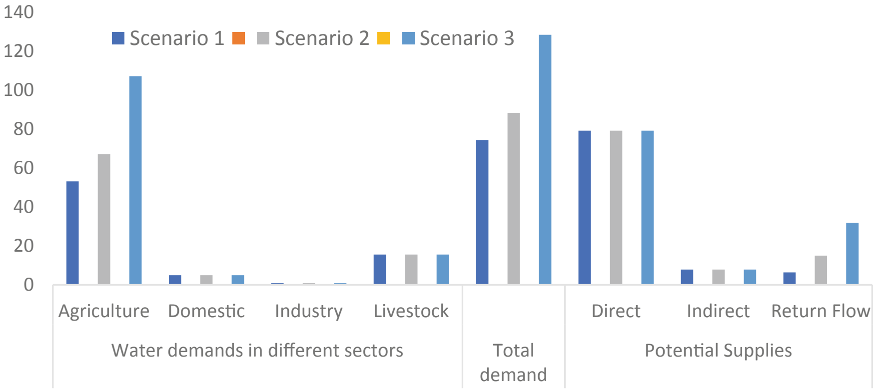

Fig. 1 Future water scenarios of India: 2040

industrial water demand in 2040 was estimated to be 4.92 M ham (i.e. 18.86 × (1.03) ˆ30 × 0.67).

Using the above assumptions, it is projected that by the year 2040, the food grain requirement of the country would grow to 307.6 m. ton. A substantial proportion has to be produced within the country to ensure food security. As stated above, wheat and rice constitute 80% of our diet and therefore ensuring sufficient production of wheat and rice would be the key to food security. Sugarcane is another crop which takes significant proportion of the water for irrigation. The consumption of sugar is around 21 kg per capita per annum in 2017–18 (source: USDA, 2018) from 13 kg in 1997), and we expect it to become 25 kg per capita per annum by the year 2025, and we assume that the consumption would stabilize thereafter. To meet this level of consumption, India needs to produce around 487 million ton, assuming that nearly 25% of the cane would go for jaggery making. The production of sugarcane stood at nearly 352 million ton from an area of 4.95 m. ha, with an average national-level yield of 71.1 ton/ha (MoAFW, 2017). The increase in production has to come from expansion in irrigated sugarcane and increase in crop yield.

Major share of irrigation water goes into the production of wheat, rice and sugarcane. The irrigation water requirements for these crops are estimated based on of the assumptions provided under point #7 of Sect. 3.1. As per the estimates, the total water requirement for producing 307.4 million ton of cereal (wheat, rice and pulses) and 486.5 m. ton of sugarcane in 2040 is 44.26 M. ham. Adding the water requirement for other agricultural produce such as oil seeds, fruits and vegetables, assumed on an ad-hoc basis, as 20% of the water requirement for major crops, the total water requirement in 2040 is estimated to be 53.11 M ham. Water requirement for rice production alone accounts for 42.4% of the total required for agricultural production. The high-irrigation water requirement for paddy production has serious implications for our ability to manage future water scarcity problems as the conventional water efficient irrigation devices do not work for this crop. Water requirements for wheat and sugarcane production were estimated to be 28.1% and 12.80%, respectively, of the total water requirement. It is to be emphasized here that most of this future demand for irrigation water will be affected in the water-scarce regions of the country which have vast areas of arable land lying un-irrigated (such as Telangana, Rayalaseema region of Andhra Pradesh, western Rajasthan, Madhya Pradesh, Tamil Nadu, Karnataka and Maharashtra) and not from the water-rich regions (comprising UP, Bihar, West Bengal and Assam) which already witness intensive crop cultivation (GOI, 1999; Kumar et al., 2012).

Our estimates show the total water requirement for human use, animals, industrial production and agricultural production to be 74.38 M. ham in the year 2040. A salient feature of the estimates is that domestic water requirements would constitute a significant portion of the total water supply requirements for various uses (20.8%). A major share of the future water requirement for domestic uses comes from urban areas–around 9.84 M ham. The large urban centres (metros with population above one million) constitute pockets of concentrated demand for large quantities of water. As seen by recent research, these demands will have to be met by exogenous sources, as these cities are mostly located in water-scarce regions of the country and the local sources there (rivers and aquifers) cannot supply such large quantities of water (Mukherjee et al., 2010). This means that there would be increasing need for reallocating water meant for irrigation.

These estimates, however, do not factor in the indirect demand for water to clean the natural freshwater reserves, which are polluted and contaminated by industrial effluents and municipal waste. The water required for pollution assimilation and other environmental services could be much more than the consumptive water use by industries. Under a situation of reduced water consumption in urban areas, the total water requirement would drop to 71.81 M ham.

In the second scenario, we assumed that the irrigation (conveyance) efficiency would be only 65% (instead of 80% assumed in the first scenario), and that the storage loss of cereals would be around 15%. The total grain requirement was therefore estimated to be 332.9 m. ton. All other assumptions used for the first scenario were kept the same for this scenario as well. Under this scenario, the total irrigation water requirement went up significantly, to 67.12 M. Ham from 53.11 M. ham, an increase of around 26.3% from the base case scenario. However, under the second scenario, the water requirement for industrial and livestock sectors would remain the same as that of the first scenario. The total water requirement as per this scenario is 88.38 M. ham. Under the situation of reduced water requirement in urban areas (i.e. 135 lpcd), the total water requirement would drop to 85.81 M ham.

In a third scenario, we assumed that the irrigation conveyance efficiency would remain unchanged from the 2015 scenario (i.e. 55% as considered by Kumar, 2010), and there would be no increase in the yield of the three major crops, viz. wheat, paddy and sugarcane from that considered in the base scenario. Also, it was assumed that the storage loss of food grain would remain at 15%, with the result that the grain production requirement will be 332.9 m. ton as in scenario 2. With the lowest conveyance efficiency, under this scenario, the total agricultural water supply requirement shot up to 107.15 M. ham, from 53.11 M. ham under the most optimistic scenario, just double. The total water requirement under this scenario was estimated to be 128.41 M. ham. Under the situation of reduced water requirement in urban areas, the total water requirement would drop to 125.84 M ham.

The estimates of irrigation water requirements, with break up for paddy, wheat, sugarcane and cash crops under three different scenarios for 2040, are given in Table 1. The estimates of water requirements in the four sectors under the three scenarios discussed above are presented in Table 2.

Table 1 Projected water requirements in agriculture in M ham (2040) under three scenarios

S. No	Scenario #	Rice	Wheat	Sugarcane	Total food	Oil seeds	Grand total
1	1	22.51	14.93	6.81	44.26	8.85	53.11
2	2	29.16	18.42	8.36	55.93	11.19	67.12
3	3	48.52	27.42	13.26	89.20	17.86	107.15

Source Author's own estimates

Table 2 Projected future water requirements in four major sectors in M ham (2040) under three different scenarios

Scenario	Agriculture	Domestic	Industrial	Livestock	Total	Total (with reduced urban water consumption)
1	53.11	15.52	4.92	0.815	74.38	71.81
2	67.12	15.52	4.92	0.815	88.38	85.81
3	107.15	15.52	4.92	0.815	128.41	125.84

Source Author's own estimates

Researchers have tried to predict future water scenario of India and had come up with estimates of future water requirements in India using various methodologies (see Rosegrant et al., 1999; Seckler et al., 1998), the most recent being the estimates by David Seckler and others from the International Water Management Institute (IWMI), Colombo. The IWMI's estimates were part of the study carried out to assess global water scarcity using a demand-based approach. The estimates were for three major sectors, namely agriculture, domestic use and industry for the period from 1997 to 2025. The estimate of future agricultural water requirement assumed that the net irrigated area per capita would remain the same. With this assumption, the irrigation water requirement was estimated for two scenarios. The first "*business as usual*" scenario assumes the existing irrigation efficiencies would continue till 2025. The second scenario assumes that the country would achieve irrigation effectiveness of 70% of their gross irrigated area by the 2025. For domestic and industrial purposes, they have assumed a basic per capita requirement of 40 M^3 per annum throughout the projection period (Seckler et al., 1998). Therefore, the only driver of change they have assumed in their demand projections is the population growth. While in our projections, the drivers of change are population growth, growth in per capita income levels, growth in industrial production, the change in food consumption levels, irrigation efficiency improvements and reduction in food losses.

Kumar (2010) had projected India's future water demands for various competitive use sectors for the years, 2010, 2020 and 2025. As per the author's projections, the total water demand from four key sectors (viz. irrigation, domestic use, industrial use and livestock use) was 104.50 M ha. m. Of these, irrigation accounted for 81.1%; domestic use accounted for 8.89%; industrial sector accounted for 10.2%. The estimation considered a conveyance efficiency of 55% in surface irrigation systems and 100% in well irrigation systems. It also considered a per capita food grain requirement of 500 g per day and a grain storage loss of 15%.

Our projections, however, do not consider the water demand for meeting the environmental flows to maintain the ecosystem health. This emerging demand sector cannot be ignored, especially when we consider the fact that the income elasticity of environmental resources keeps increasing with increasing per capita income levels (Rosegrant et al., 1999). One should mention here that whereas in developed economies, the demand for water to meet the environmental flow requirements in streams, rivers and lake systems for protecting freshwater ecosystems has become a priority in the recent decades (Pittock & Lankford, 2010), this is not the case in developing economies. In countries like India, the concerns of national food security and rural livelihood over-ride the ecosystem health concerns, and as a result, agriculture is in direct conflict with nature in many agriculturally prosperous regions.

The environmental flow requirements are not going to be uniform across the country's river basins. It depends on the natural flow regimes and the degree of alteration that had occurred to the same due to human interventions (Smakhtin & Anputhas, 2006; Smakhtin et al., 2004). In semi-arid and arid regions of the country, particularly in peninsular, western and north-western India, over-appropriation and over-allocation of stream flows in rivers to meet the increasing water needs for agriculture had resulted in drying up of stream channels in the lower reaches. Some of the examples are Sabarmati and Banas rivers in Gujarat, Cauvery River in Tamil Nadu, Krishna River in Andhra Pradesh and Indus River in Punjab (Kumar, 2010; Kumar, 2018a). Changes in land use with replacement of natural catchments by cropped land and increasing groundwater draft had also contributed to this (Wagner et al., 2013).

In sum, the water needs for ecosystem health are likely to be very high in the above-mentioned regions (Smakhtin & Anputhas, 2006; Smakhtin et al., 2004). A study by Smakhtin and others developed a water stress indicator for major river basins of the world based on degree of exploitation of water resources, and it shows that the river basins in the entire western, and most of peninsular and north-western India, and parts of central India are "over-exploited", while some pockets in peninsular and north-western India are heavily exploited (Smakhtin & others, 2004 as cited in UNDP, 2006: Map 4.1, pp. 140). It shows that the environmental flow requirements would be highest in peninsular India and western India.

This apart, many rivers in the south and western parts of the country increasingly face problems of heavy pollution from industrial and municipal effluents (CPCB, 2012). Though pollution of Ganges River had received enormous attention by politicians and policy makers alike in the recent years (see, Narain et al., 2018; Ramachandran, 2014), the problems are not very serious in the Ganges as its ecosystem has high carrying capacity. Additional water would be required to assimilate this pollution. This demand again is a function of economic growth and income levels. While in the initial stages of economic growth, the environmental pollution seems to be the price countries pay for growth at higher levels of economic growth, the investment to reduce pollution through environmental management technologies would go up, as demonstrated by the experience of European economies.

4 Balancing the Demands of Water in Different Sectors with Potential Future Water Supplies

Here we deal with four key sectors of water use that are competitive, viz. irrigation for crops; livestock water use; rural and urban domestic water use and industrial water use. It must be stated that the projection of water supplies to meet future demands of water in these sectors for a country like India is an enormous task. The future water supply potential is dependent on three important factors: (1) the ultimate water resource utilization potential of our country; (2) the status of development of water resources as on today; (3) the historical growth trends in water development; and (4) constraints induced by poor arable land availability for irrigation expansion in regions with abundant groundwater and poor groundwater endowment in regions of high demand growth. But assessing the ultimate water resources potential (UWRP) is not easy as it would be decided by: (1) the advancements in water resource engineering, particularly hydraulic engineering, given the huge gap that exist between the total annual water resources and the currently estimated UWRP and (2) the changing societal value of water which determines the willingness of the government to invest in water resource development projects. Both are time dependent. The growing concerns about the social and environmental costs of water development projects and the emerging problems associated with water resource exploitation (Cosgrove & Loucks, 2015) were also considered while extrapolating the historical growth trends to arrive at the future levels of exploitation.

The Central Water Commission estimates the total renewable freshwater falling in the country's landmass to be 400 M ha-m, contributing a total annual runoff of 180 M ha-m. According to CWC, nearly 38% of this runoff (68.4 m. ham) could be harnessed by conventional technologies (GOI, 1999). Out of this, a total of 45 m. ham (450 BCM) of surface water is already utilized through various storage and diversion schemes in India, though the reservoir storage capacity in the country is a little less than 220 BCM. The recent estimates show that surface water potential of India is 153.36 M ham at 75% dependability, while the mean annual surface water resources is 193.36 M ham, excluding the contribution from Nepal and Bhutan (CWC, 2017). The average annual groundwater recharge is estimated to be 45 m ham. Considering the physical sustainability goals, utilizable groundwater is therefore 45 m ham. Of these, around 23.2 m. ham of groundwater resources are tapped annually through wells (GOI, 2017). Hence, out of the ultimate utilization potential of 113.4 m. ham of water, only 68.2 m. ham of water resources are currently developed.

That said, there is wide variation in water resource endowment of the country. A major share of the available surface water resources (around 55%) are in the Ganga Brahmaputra–Meghna River systems. The remaining 45% is in the Indian part of Indus, and in the river basins of central India, east India and South Indian peninsula (CWC, 2017). A large proportion of the renewable groundwater resources are also in the Indo-Gangetic alluvium and peninsular India and western India, mostly underlain by hard rocks, account for a small percentage (Bonsor et al., 2017; CGWB, 2014).

Though there has been a slowdown in the growth in surface irrigation potential witnessed during the 80s and 90s due to growing environmental concerns and lack of finance to complete the ongoing projects (Kumar, 2010), during the last decade, it has picked up with a renewed interest in completing the ongoing projects. Under the Accelerated Irrigation Benefits Programme (ABIP), the State Governments have been provided an amount of Rs. 585.037 billion as CLA/Grant under AIBP (MMI) since its inception till March 2016–17. After commencement of this Programme, 143 major/medium irrigation projects have been completed and 5 were foreclosed out of 297 projects taken up under the programme so far. The irrigation potential of 8.554 m. ha has been created through major/medium AIBP projects. During 2016–17, Central Assistance (CA) of Rs. 33.08 billion has been provided to various projects under AIBP. Further, 16 projects have been included in the scheme of National Projects (MoWR, RD & GR, 2017). The Sardar Sarovar Narmada project, which is to provide additional irrigation to the tune of 1.8 m ha, is the most striking example. Significant progress has been made in completing the project during the past 10–15 years, more importantly during the last four years (Jagadeesan & Kumar, 2015). Kaleshwaram mega-water lift project being built on Godavari River, which is targeted to irrigate 1.54 m in the newly formed state of Telangana and supply drinking water to the city of Hyderabad, is the most recent example (Rishi Kumar, 2019).

Three factors are considered for assessing the future growth trends in groundwater utilization potential. First in areas where groundwater resources are abundant such as the Indo-Gangetic plains (Bonsor et al., 2017), the growth would continue to below. The reason is that there is no scope for intensifying irrigation in western parts of IGP where irrigation has already reached a stage of saturation (Kumar et al., 2008). Whereas in eastern parts, high rates of poverty in rural areas and the poor availability of additional land which can be brought under irrigation owing to ecological factors would limit growth in well irrigation (Kumar et al., 2012). Second are the arid and semi-arid regions such as western India, north-western India and peninsular India, which are facing problems of over-development. The over-exploited and "dark" blocks are unlikely to contribute to future growth in well irrigation (GOI, 2017). Third: the increasing number of legislations and regulations on the use of groundwater will have some impact on its future withdrawal (Kumar, 2010).

Therefore, we do not expect any direct growth in groundwater irrigation in the coming decades using the natural recharge available in different regions. The only possibility is in the induced development of groundwater using the augmented recharge resulting from surface water transport to the semi-arid regions. Considering these factors, it is assumed that the surface water utilization potential would grow to 82% of the ultimate potential by the year 2040, with the annual growth rate pitched at 0.5 m. ham (5 BCM per annum) for 22 years. In sum, a total water utilization potential of 79.2 m. ham ($45 + 22 \times 0.5$ m. ham of surface water + 23.20 m. ham of groundwater) is expected. The additional surface water transferred for irrigation would result in augmentation of groundwater in peninsular and western India, through irrigation return flows. Since the amount of recharge from imported water in canal commands depends on the type of crops irrigated, quantification of this component of hydrology is not attempted. Irrigation return flows will be very high for paddy fields that can be watered by gravity systems (Ahmad et al., 2004; Singh, 2005). Though this water would actually add to the groundwater resource base in the water-scarce regions, we assume that it would help recover the water table and improve the sustainability of well irrigation in those regions rather than adding to the water supply potential.

Going by the current thrust by governments to improve the environmental conditions of urban areas, we anticipate that wastewater generated from the drinking water

Table 3 Project future water supply and demand balance (2040) under three different scenarios

Scenario	Total water supply requirement (M ham)	Total water supply from surface and groundwater systems (M ham)	Total water available from canal seepage (M ham)	Total effective water supplies (M ham)
1	74.38	87.10	6.395	93.495
2	88.38	87.10	15.01	102.110
3	128.41	87.10	31.85	118.950

Source Author's own estimates

supplied to cities and towns during the year 2040 would be treated and supplied back to agriculture, and the farming communities would be willing to pay a premium for this treated water given the great economic opportunities available through high value agriculture (Amerasinghe et al., 2013; Kumar, 2018b). If the cities are situated in regions that are facing extreme water scarcity, it is quite likely that most of this water would be recycled back to augment urban water supplies by 2040. If all urban water demands are met from the available supplies, the total amount of wastewater available from cities/towns for treatment and reuse would be around 7.87 m. ham (80% of the 9.84 m. ham of water). Hence, against the future water requirement, the total effective utilizable supplies would be 87.1 m. ham. In addition to this, under all the three future demand scenarios, there would be canal seepage, contributing to groundwater recharge. They were estimated as 6.395 M. ham under scenario 1, 15.01 M. ham under scenario 2 and 31.85 M. ham under scenario 3, respectively. As is evident from the figures, the resource availability through canal seepage will be highest under the low conveyance efficiency scenario (i.e. scenario 3).

The overall water supply–demand balance under the three scenarios is presented in Table 3. It is seen that in the first two scenarios, the available supplies would be able to adequately meet the water requirements and only in the case of third scenario, there is a supply deficit, i.e. to the tune of around 9.45 M ham. However, this is the most unlikely of the three scenarios, because this scenario assumes that there will be no growth in crop yields. Such a situation of yield stagnation is very unlikely. With growing economic power, the country is likely to witness greater investments in agricultural research, particularly when we consider the fact that the direct economic, social and environmental costs of building new water projects to augment the supplies are likely to be prohibitively high.

5 Technology, Governance and Environment

While we make efforts to meet the emerging water challenges through investments in augmenting the surface water supplies and managing the demand for water in various sectors, the improved water security achieved therein would drive development (Grey & Sadoff, 2007) and economic growth (Barbier, 2004; Grey & Sadoff, 2007).

The changes in economic conditions are likely to drive changes in the technology adoption in the water sector, governance of water and overall water environment (World Economic Forum, 2018).

Among the various governance challenges in the water sector, the challenge in dealing with transboundary water issues are greatest. Transboundary rivers are common features of today's hydrologic and political landscape. Within different regions/provinces that share a river, it is vastly beneficial to come to an agreement on how to share the water in times of stress before that stress occurs rather than to work out such agreements during times of stress (Cosgrove & Loucks, 2015). Foreseeing the large economic and social benefits that water development can produce, the Indian states are likely to witness greater cooperation for sharing of water from the inter-state river basins and renewed interest in the transfer of water from water surplus states to water-scarce states The plan to set up a permanent tribunal through the passing of an Inter-state Water Disputes Amendment Bill (2019) for adjudicating on water disputes is one such step on the governance front. Another such step is the initiative of the Union Water Resource Ministry to get certain water surplus states to agree on water transfer proposals, conceptualized under the National River Linking Plan, and the plans to enact a new national law on water that would bring water in the Union list. Unlike in the past, in India, the same political party is in power since 2014 at the centre and several provinces. Under such circumstances, the said initiative of the centre is likely to bear fruit.

Similarly, while the cost of building new irrigation schemes is likely to be high (in terms of cost per ha of land brought under irrigation and the resource cost), with improving economic conditions of the farmers who benefit from the services that are provided, even expensive water would increasingly become affordable. The gradual shift in cropping pattern towards high-value crops, including fruits, vegetables and dairying in the recent years resulting in an impressive growth in agricultural GDP (Rada, 2013), increased the economic value of water in agriculture. This combined with the need for improving the quality of irrigation would result in greater willingness on the part of irrigation bureaucracies to invest in improving the technical efficiency of irrigation systems so as to manage irrigating larger area with lesser amount of water as their revenue from collection of water charges increase. Such investments will also become necessary to justify the huge investment in building the basic infrastructure for irrigation such as reservoirs and water distribution systems. In such cases, there would be greater investments to improve conveyance efficiency with the use of underground pipelines for water delivery instead of open channels. The states of Karnataka, Rajasthan and Gujarat are already making large capital investments for installing underground pipelines for water conveyance and micro irrigation systems for water application on the farms in the some of their irrigation commands to improve the technical efficiency of water use.

Needless to say, the increasing scarcity value of water and the ever-increasing demand for the same from industry and urban domestic sector would demand greater accountability from irrigation bureaucracies, thereby forcing them to constantly improve their operating efficiency to reduce the amount of water they divert from the river basins for agricultural uses. New institutions are likely to emerge in the water sector for allocating water from river basins and for resolving conflicts, as competition between various water use sectors increase over water use (Grey & Sadoff, 2007). The setting of a Water Resources Regulatory Authority by the state government of Maharashtra in 2006 for managing inter-sectoral water allocation and regulating water withdrawals by each of the large-water consuming sectors under the Maharashtra Water Resources Regulatory Authority Act-2005 (https://mwrra.org/wp-content/uploads/2018/07/MWRRA-Act-Regulatory-English.pdf) is just one example.

As the demand for fruits and vegetables increase in the market and farmers start growing such high value crops (MoAFW, 2017), that are generally water-sensitive, the future demand would be for high quality irrigation. As marginal returns are likely to be high, farmers would be willing to pay high price for this water. As a result, the irrigation bureaucracies are likely to promote adoption of water storage systems that control water delivery in the field, and precision irrigation systems to improve water use efficiency among farmers in the irrigation commands, through capital subsidies. However, real improvements in water use efficiency through introduction of such precision irrigation systems would be affected for distantly spaced crops in arid regions with deep water table conditions (Kumar & van Dam, 2013),

On the other hand, increasing per capita income and the consequent growing demand for environmental management services would force water bureaucracies to free increasing proportion of the renewable water earlier appropriated by them from rivers for irrigation and municipal water supply for ecological needs. Out of the 30 world river basins identified as a global priority for the protection of aquatic biodiversity (Groombridge & Jenkins, 1998), nine are in India and attract immense attention due to their extensive and continuing development. These basins are the Cauvery, Ganges–Brahmaputra, Godavari, Indus, Krishna, Mahanadi, Narmada, Pennar and Tapi. Except for the Ganges–Brahmaputra, all these basins have also been categorized as "strongly affected" by flow fragmentation and regulation (Nilsson et al., 2005). With greater willingness among the urban dwellers to pay for clean environment and water for recreation, and the increasing scope for reuse of treated wastewater in agriculture and investment cost recovery (WWDR, 2017), greater investments are likely to be witnessed for environmental management technologies (such as wastewater treatment systems) in the urban areas that would clean up the lakes and rivers, reduce the demand for freshwater to meet irrigation needs and recover nutrients and energy from the wastewater. This will be complemented by emergence of new water quality regulations or (pollution) tax for control of water pollution. Simultaneous changes are likely to be witnessed in the institutional environment governing water use in Indian cities. Since the cost of importing water would be high, the urban water utilities will be encouraged to invest in technologies to reduce system losses, thereby reducing the cost of water supply. On the other hand, consistent improvement in the economic conditions of urban dwellers would increase the ability of utilities to start metering all water connections and price water at levels that reflect the scarcity value of the resource. Such prices will induce efficient use of water, thereby reducing the overall demand.

6 Concluding Remarks

The estimates of water requirement and supplies for the year 2040 presented in this paper for three different scenarios are first-cut estimates and have several limitations. *First* they do not consider the recent economic boom in the country and its impact on water conservation. In the recent past, many water-scarce areas of Indian countryside had experienced a boom in adoption of micro-irrigation systems with institutional financing and new subsidy structures. For instance, area under drip irrigation had increased from 3,67,000 ha in 2000–01 to 3.30 m. ha in 2015–16 (Moin & Kamil, 2018). *Second*: Indian agriculture is also becoming export oriented and is getting slowly diversified into horticulture, vegetables, floriculture and fisheries (MoAFW, 2017; Rada, 2013). This would also mean that the farmers' preference for traditional cereals and pulses would decline, at least in agriculturally prosperous regions, if they increasingly experience physical scarcity of water. This can reduce the water requirements for generating the same amount of agricultural wealth. *Third*, in the analysis, we have not considered the increased water demand due to changing food habits, other than that which is caused due to changing composition of grain intake. With increasing preference for meat and milk-based food products, an impact of economic growth and rising income levels, the overall water requirement would go up, even if we assume that the calorie intake would remain almost the same. This is because the water requirement per unit calorie intake would be much higher for meat and milk-based food products than cereals and vegetables (Alexandratos & Bruinsma, 2012; Mekonnen & Hoekstra, 2012). For instance, water footprint for kilo calorie of chicken meat is 3 L and that for bovine meat is 10.2 L, while that for cereals is around 0.5 L (Mekonnen & Hoekstra, 2012). However, we have not considered any major change in food habits in our assessment of grain requirements, and resultant water requirement.

Nevertheless, from a practical perspective, the two assumptions made by us, i.e. about food self-sufficiency (that cereal demand for direct consumption will have to be met from production inside the country), and about food consumption pattern, will not induce much error in estimation of water demand. This is because: [1] there would be an increase in demand for cereals as cattle feed and poultry feed, which could even offset the reduced demand for cereals for direct consumption; and, [2] the growth in aggregate demand might force country to import feeds to meet the grain deficit.

Our estimates suggest that if we are able to keep pace with the ongoing economic development in the country with rapid public investments in water resources development and agricultural research, we will be able to meet the water and food demands of 2040, even with low levels of improvement in efficiency of water conveyance, and with high degree of loss of food grains. The estimated future water demands under the first two scenarios are much less than the estimates currently available from various sources (see for instance, GOI, 1999). Therefore, future investments in agricultural research to develop varieties that produce high yields without increasing consumptive water requirement, and that are flood, drought and salt resistant through plant genetics would yield high social, economic and environmental returns (Kijne, 2001). This is extremely important for regions where the yield potential is not realized for major crops, due to agro ecological reasons. For instance, while genetic yield potential of paddy and wheat is realized in Punjab and Haryana in the farmers' fields, in large paddy-growing areas of Bihar, the average yield obtained is very low with a very high yield gap due to ecological factors, mainly floods, waterlogging and salinity and poor incidence of solar energy (Pathak et al., 2003).

But we should also reckon with the fact that conveyance efficiency improvements in irrigation will have adverse 'third-party effect'. Higher levels of efficiency in conveyance systems of irrigation schemes mean less amount of water available in shallow aquifers from canal seepage, etc. that can be effectively recycled to meet local water needs using wells and pump sets (Perry, 2007). Hence, such interventions can adversely affect the well-owning farmers who depend on this water. However, this is hardly recognized by India's water planners as is evident from the great emphasis given to improvement in engineering efficiency of irrigation schemes (see, GoI, 2013). Further, though such measures would help defer investments for building more surface storages in near future, they would ultimately reduce the effective water availability for meeting the local water needs by drying up underground sources and drainage channels.

Hence, priority should be on research on plant genetics to develop varieties that transpire less water while producing same or more yield (Kijne, 2001). On the other hand, augmented supplies of water to meet the growing needs of cities would add to the quantum of wastewater generated (Kumar, 2018b). If treated, this can add to the country's overall water balance, meeting the irrigation water demands in the peri-urban areas. With increasing application of economic and business models by integrating the considerations of reuse of treated water, and resource (energy and nutrient) recovery with public health concerns in investment decision making (WWDR, 2017), large-scale investments are likely to come up in the wastewater treatment sector.

Overall, consistent improvement in the water situation through measures for improving water supplies and managing water demand will create favourable conditions for faster economic growth in the country. The same growth will demand better technologies of water use and improved governance mechanisms to further improve efficiency of water use on the one hand and better environmental conditions on the other.

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