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Assessing the Impact of Water Resources Vulnerability under Climate Change in India

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Abstract

The present paper focuses on the relationship between the climate change and the emerging water supply and demand situation in India. The relationship between Himalayan Glaciers-Runoff, river discharge and climate change and its effect on the surface water supply situation in the northern part of India has come under stress due to rise in temperature and retreat of almost all Himalayan glaciers. The groundwater levels across India especially in the Northern rice growing states of Punjab and Haryana are declining at the rate of 0.7–1.2 meters per year. The emerging surface water supply and demand conditions by different sectors clearly establishes the fact that by 2050 the resulting deficit and water gap situation would worsen as compared to the already stressed present situation. The need of the hour is to improve the productivity of the existing water resources and reduce the water intensity of agriculture and allied activities. Water has no substitute and its scarcity invariably causes conflicts which would have serious social and economic consequences with no remedy in sight.

Keywords: Climate change, Hydrological cycle, water demand and supply, surface water, groundwater, water deficit

1. INTRODUCTION

Climate change, as defined in terms of increase in temperature and rising variability in precipitation is now an established reality. These climate changes are bringing about far-reaching consequences for the mankind and the conditions under which we live. Water resources are influenced by changes in agriculture and land use change, cropping intensity, carbon dioxide emission and supply and demand conditions. Water use and demand has increased rapidly in last few decades due to population and economic growth. Increased water supply due to better water management and increase in use efficiency has provided adequate inputs to growth in agriculture with irrigation being the biggest user of water resources. Over 600 million farmers in India depend on agriculture for their living and nearly two-thirds of land under cultivation has no irrigation and is classified as rain-fed areas. Only 40% of the total cropped area is under irrigation by surface and groundwater resources. Impact of climate change on the present and future ground water availability and recharge is estimated to be critical for sustainability of agriculture sector in India.

2. CHANGES IN HYDROLOGICAL CYCLE, WATER VAPOR CONCENTRATION AND CLIMATE CHANGE

Water, hydrological process and climate change are intimately correlated, and the hydrological sector is at the heart of climate change and its impact. The hydrological cycle is linked with changes in atmospheric temperature, water vapor and net radiative balance. Climate changes has caused irreversible changes in the working and systemic components of the hydrological cycle. These include changes in precipitation patterns, their intensity and extremes events leading to droughts and floods. Glacial melting and loss of snow cover, rise in atmospheric water vapor, fall in soil moisture and increased runoff leading to soil erosion are other leading derived indicators of climate change. The increases in variation and uncertainties of precipitation at the global level are synonymous with increased atmospheric water vapour which is the main indicator and constituent of observed global warming. Total water vapour globally has increased over the oceans by $1.5 \pm 0.3\%$ per decade from 1980 to 2014 which is consistent with rapid changes in sea surface temperature [1]; [2].

3. HIMALAYAN GLACIERS-RUNOFF, RIVER DISCHARGE AND CLIMATE CHANGE

The most important factors influencing water supply and demand are precipitation, temperature and evaporative demand by natural vegetation. River basins are the major source of surface water resources and the change in total annual river runoff amount is expected to increase with regional variations in climate. Changes in river flows and runoff due to climate change will depend on changes in the volume and timing of precipitation. CO_2 enrichment and increase in fertilization rates due to climate change will lead to reduced evaporation and would leads to higher growth rate in the volume of runoff especially in water scarce areas of Western and Peninsular India. Runoff rates will change by 2- 5 mm/day in wet regions and from 0-0.2 mm/day in hot and humid regions of India [3]. Northern Regions in India which are critically dependent upon perennial rivers of Himalayan regions for agricultural production would be adversely affected by retreating and rapidly depleting. Retreat and melting of these glaciers due to global warming would lead to increased water flows in the river system initially in the short term but the volume of water flows into the river system would fall in the long term [4]; [5].

The Himalayan Rivers like Yamuna, Ganges and Brahmaputra are very highly susceptible to climate change because snow and glacier water in summer months of May to September make up for a substantial contribution to their runoff [6]; [7]. The volume of snow water melt is determined by the magnitude of snow fall, the rate at which the snow melts, the amount of rain that falls during the melting period and temperatures at that time. The peak snow melting season in the Himalayas coincides with the summer monsoon season and intensification of monsoon and extreme events would raise the snow melting rate. This would imply increase in water in the summer months which would ultimately cause increased flooding and more water in the river system in the short run [1]. The increase in temperature would shift the snowline and the snow-covered areas backward which would severely reduce the capacity of the glaciers to hold snow for the summer months. This phenomenon increases the risk of flood in the catchment areas of Himalayan region seriously affecting the agricultural crop in the northern plains of India. A runoff sensitivity analysis showed that a 1-2ºC rise in temperature would cause a 5% decrease in runoff, while a 4ºC rise in temperature and 10% decrease in precipitation and would cause a 40% decrease in the runoff of in the Ganges River in north India [8].

In rivers where main source of water is from glaciers, the runoff would first increase due to rapid melting of glaciers due to rise in surface temperature and consequently more water is released in the downstream river basins. Summer and dry season flows will than decline to well below the threshold levels threatening the viability of several perennial river systems in northern India. About 60% of the summer season flow of the Ganges River is supplied by the catchments flows in the Himalayas which will be badly affected by the decline of snow line of glaciers like Gangotri etc. [9]; [10]. Gangotri glacier is the source of Ganges River flow water and this glacier has retreated by almost 23 km in the last 50 years. Time series and sensitivity analysis of river runoff in the Himalayan belt showed that the runoff increase due to melting of glaciers was higher than the precipitation increase under the assumption of no temperature increase [11]; [12].

4. HYDROLOGY, GROUNDWATER AND CLIMATE CHANGE

The estimated total replenishable groundwater resource in India is 433 billion cubic metres (BCM) per year as per Central Ground Water Board. Out of this, 399 BCM is available for utilization for different sectors and thus leaving about 34 BCM for natural discharge and recharge. The total ground water draft is 231 BCM of which 92% is for irrigation (213 BCM) and 8% is for domestic and industrial use (18 BCM) [10]. The groundwater available for irrigation is estimated to be about 92 per cent of total groundwater resource available or about 403 BCM and about 8 per cent for domestic, industrial, and other uses. Out of this the utilizable groundwater, resource for irrigation is 382 BCM which is almost around 88 per cent. The annual net draft is estimated to be about 212 BCM [8].

Groundwater systems are dynamic in nature with annual recharge and extraction rates having both spatial and temporal variations. Groundwater level and its consequent extraction are determined by accessibility, water quality, land use and geophysical conditions. Climate change and its variability are affecting both the water quality and quantity in the system. The impacts of climate change on groundwater resources are determined by dynamic changes in water demand and groundwater extraction rates for ever increasing use by agriculture sector. Groundwater recharge is essentially a function of rainfall intensity and frequency, run-off rate, and surface temperature. In tropical areas, semi-arid and dry regions the groundwater recharges decrease with an increase in rainfall due to higher temperatures and higher evapotranspiration rates. The earth first gets saturated with water before the extra water can percolate down to the deep channels and aquifer system for storage [36].

The increasing dependence on ground water as a reliable source of water has resulted in indiscriminate extraction leading to rapid depletion in several areas like in Punjab. This has created severe problems of water logging and soil salinity due to the steady rise in ground water levels. Though the ground water development is about 60% in India, the average stage of ground water development in North Western States is much higher (102%) when compared to the Eastern States (43%) and Central States (42%) [13]. Studies indicate that one-meter average drop in groundwater level would increase India's total carbon emissions by around 4.8% because of increased fuel consumption and electricity use [3]. Average groundwater recharge rate would decrease by 20–25% when precipitation decreases by 12.5–19% due to climate change. Water demand for groundwater is also being influenced by increasing uncertainty and variability of monsoon rainfall which is the mainstay of surface water resources in India. The specific yield of water which captures the net availability of water after meeting all the ecosystem needs in India is approx. 0.12 which translate into a decline of average of 0.25-033 meter per year at the national level. The difference between water available water for recharge and annual water extraction in the water stressed Northern region of India is creating a deficit of 13.2 km^3/ yr and in the period 2002-2008, the region lost 109 km^3 of groundwater, which is double the capacity of India's largest reservoir [14]. The low level of water use efficiency, especially of surface water in Indian agriculture which is one the causes for the low productivity levels of crop outputs. The non-elastic nature of surface water supply is primarily responsible for excessive groundwater extraction across the states of northern India in response to the growing demand for water. This excessive extraction of groundwater is impacting even the water flows to the perennial river originating from the Himalayas. In case of Ganges, the amount of water flows from groundwater to the river has decreased by almost 50% during the peak summer months when the contribution of groundwater to the river varies from 30%-70%. The water level in river basin has declined by as much at rate of 0.5 to 38.1 cm/year between the last thirty years. All the three sources of the water flow to the Ganges namely, monsoon rainfall, Himalayan glacial melt and groundwater discharge are under elevated levels of stress [15]. From 2003 to 2012, the groundwater availability fell by almost 21 Gigatonne per year. Taking North India as a whole, the groundwater availability rates declined by approximately 52 Gt/yr from the period 2002-2008 [16].

5. OVEREXPLOITATION OF GROUNDWATER RESOURCES

As per the latest assessment, out of the total of 5800 assessment units in the country, ground water development was greater than 100 % of the natural replenishment in 840 units which is approx.14.7 % of the total no. of blocks (over-exploited) [17]. Ground water development was in the region of 90-100 percent of the utilizable resources in 230 assessment units (3.9%), which have been categorized as 'Critical'. Around 550 assessment units in semi-arid and arid regions have development index of 70-100 % which is the main source of long-term secular decline in water levels. These have been categorized as 'Semi-Critical'. The main regions showing these characteristics are the rice growing regions of Punjab, Haryana and Rajasthan. Around 4080 assessment units in relatively water excess areas with level of ground water development below 70% have been categorized as 'Safe'. The overall average rate of ground water development in India is around 50-60% which exhibits a lot of spatial and geographical variation [17]. Around 240 blocks/assessment units (4%) are critical where groundwater development has crossed the threshold limit of irreversibility and the situation is beyond salvation (Table 1).

Table 1: Status of groundwater use in India

Category of ground water	**Position on**		
	1998	**2005**	**2009**
Over-exploited	255	390	840
Critical	310	420	1014
Semi-critical	16	442	556
Total	325	860	1620

Source: Central Ground Water Board (CGWB) 2015

The number of over exploited groundwater blocks in the period from 1990-2004 in the country rose to 840. This number was 260 in 1984, 390 in 1992 and 450 in 1998 showing the extent of gross overutilization and extraction of water. The overall stage of groundwater development which was 35% in 1998 rose to over 60% in 2010. Groundwater levels have shown a linear and secular decline of more than 20 cm per year in 362 districts of the country during the decade 1995-2004 [17]. Between the periods from 1970 to 1998, the land irrigated with groundwater in India increased by 110%, while the areas of land irrigated with surface water increased by only 26%. This was the direct result of starting of green revolution in India especially in states of Punjab, Haryana and West Uttar Pradesh [18]. The high yielding varieties introduced in green revolution were both water and energy intensive and the expansion of irrigation led to major changes and shifts in cropping pattern. The number of electrified wells for irrigation has increased exponentially in the last 40 years from less than one million to more than 35 million in the year 2015 [19].

6. ANALYSIS OF SURFACE WATER RESOURCES IN INDIA

Water resources are influenced by changes in agriculture and land use change, cropping intensity, carbon dioxide emission and consequently water use and demand has increased rapidly due to population and economic growth. Irrigation is the largest user of total water use globally at about 60-70% and is the most critical input for sustainable agriculture [21]. Share of surface irrigation (30-40%) in agriculture is falling due to high capital cost involved in developing new systems while that of groundwater irrigation has increased at a rate of 4% per annum from 150 million ha in 1960 to 320 million ha in 2012. This corresponds to almost 25% of global total cultivated land available for agriculture. Irrigation needs in agriculture is critically dependent and function of the four main parameters: gross irrigated area, crop type, cropping intensity and irrigation water use efficiency. The cropping intensity (which measure how many times in a year a land is used to grow crops) of irrigated land is projected to increase from 1.20 to 1.50 crops per year. This will cause a rise in carbon and water intensity of agriculture [22].

The average annual rainfall in India is 1200 mm and for the summer monsoon months is 898 mm. The surface water resources potential of the country are a direct function of rainfall and snow stock in the Himalayan Mountains. This adds to about 1869 cu. km. but the utilizable potential of the country is only about 1122 cu. km. (60%) of total available potential. The three big rivers basins of Ganga, Brahmaputra and Meghna fed by melting of Himalayan glaciers contribute to almost 40% of total water resources potential in India. The efficiency ratio which measures the utilization ratio is around 50–80% of available utilizable surface resources. Rivers such as Narmada and Mahanadi have percentage utilization ratios of 22% and 36%, respectively. The distribution of water resources in India is highly uneven and skewed and it varies from dry and semi-arid Rajasthan in western India to wet and water excess states of West Bengal and Orissa [23]. The average availability in east India is 1600 cu. m. as compared to 360 cu. m. in the dry and semi-arid Sabarmati River basin in Gujarat [24]; [25]. Average per capita annual availability for major part of India is around 1590 cu. m. About 40 percent of the population in India has 70 per cent of India's water resources while the remaining 60 per cent has only 30 per cent indicating extreme disparities in distribution [26]. The main reason is the uneven pattern of rainfall and the presence of glacier fed river system of east and north India. The actual per capita annual availability of water at 1590 cu. m is overestimated by 60-80% [27].

Analysis of a rainfall series data for the past 100 years for India does not show any clear trend and no significant shift in annual timing and duration of rainfall in India. However, analysis of the rainfall data of 1140 meteorological sub stations in India shows a clear negative trend in rainfall in parts of south India, central India, and parts of the north and northeastern regions. Rainfall data showed positive trends in for Gujarat, Maharashtra, coastal Andhra Pradesh, and Orissa. Eastern Uttar Pradesh, eastern Madhya Pradesh, Maharashtra, and other parts of northwest India did not show any changes. In the rainfed districts of India dependent upon yearly monsoon rains, 40% of the places showed a negative trend, 48% showed a positive trend, and 12% showed no changes in rainfall [28]; [29].

7. SECTOR WISE ANALYSIS OF WATER DEMAND IN INDIA

In agriculture, the net sown area (rainfed and irrigated) will remain the same at around 142 million hectares but irrigation intensity will increase from 41% to 55% percent over the period 2000-2050. This indicates inelasticity of land availability and limit of crop extension to newer areas. Increase in irrigation intensity would be primarily met by extension of groundwater irrigation to newer and rainfed areas as surface water resources are expected to remain same or decline due to climate change. Surface irrigation are will increase from 18 M ha to 28 M ha in 2025 and remain constant beyond that. Groundwater use efficiency will increase by 10 percent from the present 61 percent by 2050 while surface water efficiency will increase from the current low of 30-35 percent to around 50 percent. Domestic demand for water will increase from the current national average of 32m^3/person/year to 60m3/person/year in 2050. Industrial water demand is anticipated to increase from the current 42 m3/person/year to 102 m^3/person/ year in 2050 (Table 2). Total water demand to meet the growing needs of a growing population and economic growth is expected to increase by 26 percent in 2025 and 32 percent in 2050 [30]; [31].

Table 2: Future water demand in India

Water growth demand drivers	**2020**	**2025**	**2050**
Changes in demographic profile -Population (million)			
Urban population	1010	1410	1600
Economic growth	6-7%	7-8%	5-6%
Domestic water demand			
Urban demand (m^3/person/year)	30	42	64
Industrial demand (m^3/person/year)	44	65	100

Source: Bhattacharyya et al 2015; Amarasinghe et al 2007

8. WATER RESOURCES AND FOOD GRAIN DEMAND IN INDIA

In 2017, the per capita availability of food grain is around 490 gms per capita per day based on the total production of food grains in the country at around 273 million tonnes. The goal is to raise the per capita consumption by 10% which would imply that the total food grain requirement will increase to 300 million tons. If the population growth rate remains or even falls below that of 1.9% per annum than also, we would require around 400 million tons to feed the extra population. This would require more water fertilizers, and energy guzzling high yielding varieties of crops to be grown in water stressed areas. The area under irrigation would have to double from the present 40% to meet the overall requirement. The population of India increased at an annual rate of about 2 percent per annum in the 1990s and is expected to grow at a lower rate of 1.2 in the next decade. The population is expected to reach the peak in around 1940 and then start to decline [32]. The present agricultural practice in India requires 633 m^3 water withdrawals per person. With the addition of the extra population pressure the agricultural sector in India will require an additional 260 km^3 of water withdrawals by 2030 which represents a 45% rise over the current base figure (Table 2). The main constraints on increasing agriculture production in India are: constant land input, declining total factor productivity and the declining size of average farm holding [33].

Table 3: Projected food grains and crop area required for meeting the requirements of increase in population up to 2050

Year	**Grains (Million tons)**	**Rice (Million tons)**	**Wheat (Million tons)**	**Maize (Million tons)**	**Other Cereals (Million tons)**	**Pulses (Million tons)**
2010 (actual production)	124	44	27	7	24	22
2025 (projected)	122	46	27	10	16	22
2050 (projected)	125	51	28	20	11	18
Irrigated area as a % of total crop area						
2010 (actual)	48	48	86	22	6	12
2025 (projected)	48	56	96	38	12	17
2050 (projected)	52	58	98	35	24	25

Source: Amarasinghe et al 2005, 2006

From 1950 to 2000 the food grain production in India increased by 3.3% per annum while population increased by 2.1% per annum. This enabled India to reduce poverty levels from 40% to less than 25% in the year 2010. India became self-reliant in food grains due to higher growth productivity induced by high yielding varieties introduced after green revolution. But after 2000 the growth rate of food grains production in India declined to less than 1.5% while the population increased at the rate of 1.9% (Table 3). This has impacted the per capita availability of food grains in India which has declined from 523 gms per day in 19951 to 485 gms per capita per day in in 2017 [34].

Table 4: Growth of water demand drivers in India

Water Demand Drivers	**Irrigation efficiency ratio (%)**				
	Actual 2010	**Projection/forecast**		**Full achievable efficiency (%) with the given resources**	**Scope for increase (%) with the given resources**
		2020	**2050**	**2020**	**2020**
Surface water (rivers and canals)	35-40	40-50	50-60	20	30
Groundwater (tube wells)	50-60	70	75	75	20

Source: Amarasinghe et al 2007; CWC 2015

Higher food grain production due to better input and seed management, increases in cropping intensity and crop yields have contributed to output growth in agriculture. This main driver of growth has been augmentation of irrigation facilities in surface and groundwater. Irrigation expansion and crop yield growth have shown a clear positive and linear correlation (Table 4). The average yield of food grains increased at a compound growth rate of 2.32 percent annually between 1965 and 1995 and the ratio of irrigated grain area to total grain area has increased at an annual rate of 2.48 percent. The forecast for 2020 and 2050 indicates that the water use efficiency of both surface and groundwater would have to significantly rise to meet the future demand of food grains in India. This is because the limit of soil efficiency as measured by soil organic matter has been reached and it has become toxic due to excessive use of chemical fertilizers and insecticides [35].

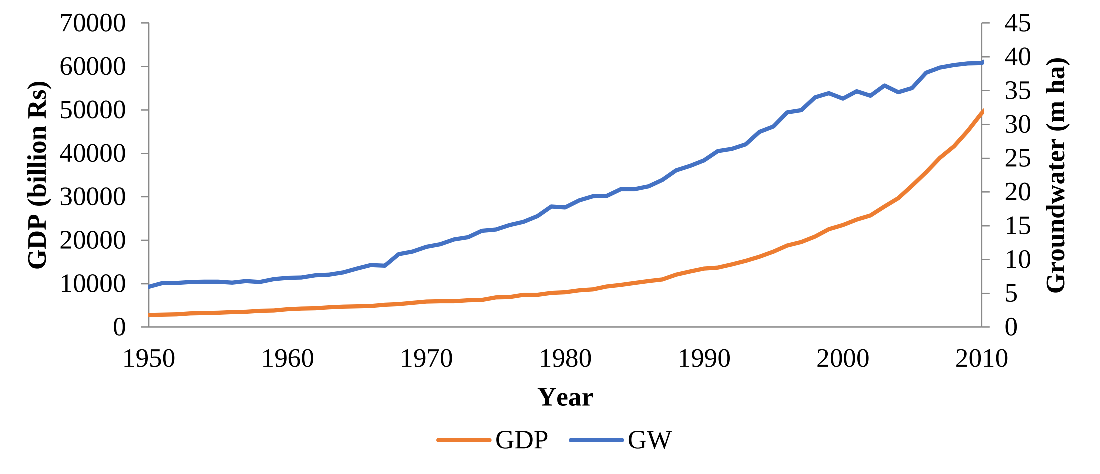
9. GDP AND GROUND WATER ANALYSIS

Gross groundwater irrigated area is expected to show double digit growth and would increase to 60 M ha by 2025 and to 70 M ha by 2050. The relationship between GDP and groundwater since shows a very linear and positive relationship (Table 1). Taking GDP as a dependent variable and ground water (M ha) as an independent variable in the following form GDP = F(Groundwater irrigated area) reveals the following relationship:

GDP (billion Rs) = -7652.814 + 1095 Groundwater irrigated area (M ha)

(0.00) (0.002)

Number of observation = 63; F (1, 62) = 259.483; Prob. > F = 0.0000; R-squared = 0.898; Adj. R-squared = 0.804



Source: CGWB 2014

GW-Groundwater; GDP-Gross Domestic Product

Fig. 1: Groundwater and GDP in India

The result of the above regression analysis shows that one million ha additional increase in area brought under ground water irrigation adds to around 1095 billion Rupees annually to Indian economy. This indicates the relative and growing importance of groundwater as source of irrigation in India. Groundwater is easily available, low cost and ready source of water for irrigation. Creating additional capacity of surface water is time consuming and highly capital intensive. Probably the limits of surface water irrigation have been reached and environmental factors and difficulties of land acquisition will prevent further incremental increase in gross irrigated area. The area under crop production has increased from 97 M ha in 1950 to 126 M ha in 2014. The irrigated area has increased from 22.56 M ha in 1950 to 92 M ha in 2015. While canal irrigated area increased from 9 M ha in 1950 to 16 M ha in 2013, the groundwater irrigated area increased from 16 M ha to 42 M ha respectively.

Table 6: Groundwater use analysis after 1950

Period	**Average increase per year in area under crop production**	**Average increase per year in gross irrigated area**	**Average increase per year in canal irrigated area**	**Average increase per year in groundwater irrigated area**
1950-2012	0.236 M ha	1.153 M ha	0.15 M ha	0.62 M ha

Source: Amarsinghe et al 2005; CGWB 2015

The average increase per year in gross irrigated area in India after 1950 has been 1.2 M ha per year which is almost thrice the average increase in total area under crop production (Table 6). This indicates the fixed nature of land availability and the cropping intensity rise after the green revolution is the now the only means of increase in production. The average increase per year in groundwater irrigated area is almost four times the average increase per year in canal irrigated area. This is in tune with the rise of groundwater as a reliable and perennial supply of irrigation water especially for rice cultivation.

10. FUTURE WATER DEMAND, SUPPLY ANALYSIS AND CLIMATE CHANGE

Gross per capita water availability in India has fallen from 1822 m^3/yr per capita in 2001 to less than 1500 m^3/yr in the year 2012 [11]. If this situation is extrapolated over the whole of India, then it is estimated that around 200 million people will experience increased water stress conditions by 2050 and the per capita availability of water in India would fall to 1120 m^3/yr (Table 7) [25]; [31].

Table 7: Average annual per capita availability of water in India

Year	Population (billion)	Per capita availability of water (m^3/year)
2001	1.03	1822
2010	1.21	1547
2025	1.4 (Projected)	1298
2050	1.5 (Projected	1120

Source: Bhat 2014; CWC 2015; Garg and Hassan 2007

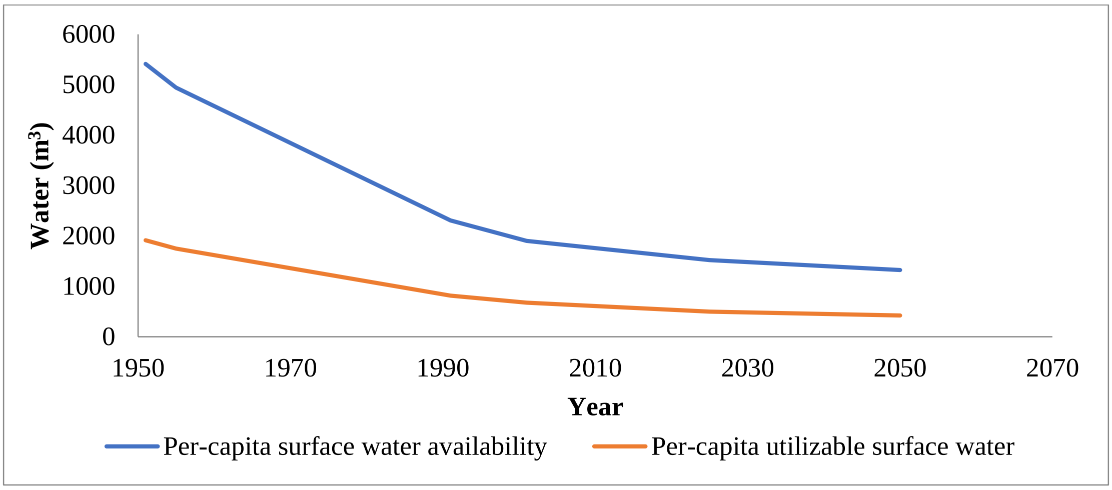
The demand for water is expected to increase by 25 % by 2030, and 40 % by 2050. Rapid economic growth and industrialization will add to the growing additional water demand from the domestic and industrial sectors. The water demand of the urban and industrial sectors will account for 10 % and 12 % of the total water demand by 2020 which would increase to 12 % and 20% respectively by 2040. The urban and industrial sectors will account for 50 % of the additional water demand by 2025, and more than 80 % by 2050. Rapid urbanization will add fuel to water demand and will be almost 50% of the total population by 2050 [30]; [36]. Higher water use intensity in urban settings would have serious repercussions for the water demand. There would be more than 840 million people in the most water deficit parts of the country compared with 320 million today (Table 8).

Table 8: Projected water requirements of India in billion cubic meters (BCM)

	1990	2000	2010	2025	2050
Domestic	32	42	60	75	100
Irrigation	437	550	690	920	1075
Industry	-	8	12	25	65
Energy	-	2	8	15	130
Others	40	40	50	75	80
Total	510	642	820	1110	1450

Source: Amarasinghe et al 2006, 2007; IWMI 2000

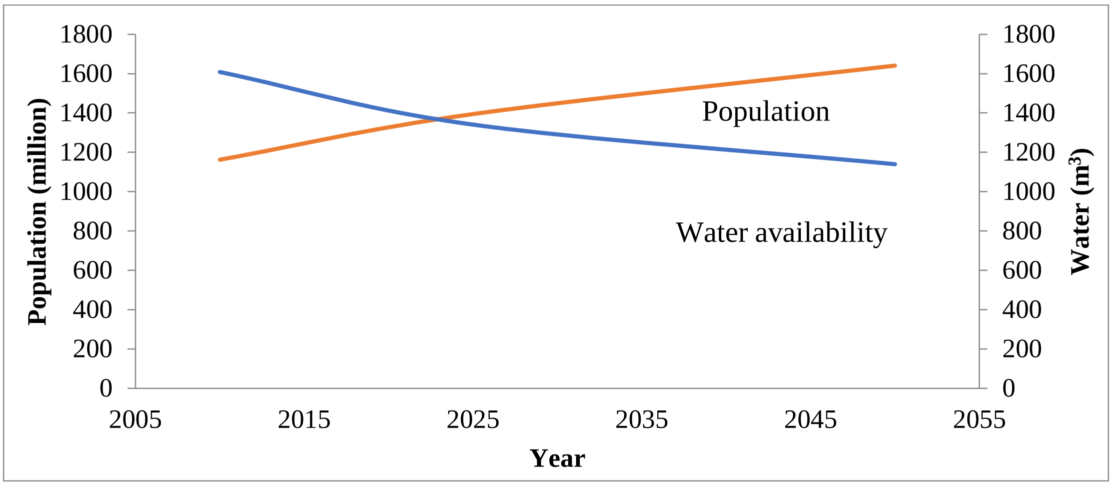
The key drivers of increase in demand of water in the future are expected to be the irrigation sector followed by domestic and industrial sector. The industrial sector is expected to record an 800% increase in water demand due to rising industrialization to 65 BCM by 2050. Agriculture sector share would be around 60% of the total water availability down from the current level of 80% [32]; [33[; [36].



Source: Kumar et al 2005; Mahmood and Kundu 2006

Fig. 2: Projected per capita per year availability and utilizable surface water in India (in m^3)

Per capita availability of less than 1700 m^3/person/yr is taken globally as water stressed situation and taken in this situation, India is already water stressed. But this hides wide variations in spatial and temporal scale in India. Availability of less than 1000 m^3/person/yr is regarded as scarce and by this criterion, India is likely to become a water scarce country before 2050 (Fig 2).



Source: Bhattacharyya et al 2015; Mahmood and Kundu 2006

Fig. 3: Per capita availability of water and population growth

In India, the availability of surface water in the years 1991 and 2001 were 2309m^3 and 1902 m^3. But by then the adverse impacts of climate change had started showing their results and it has been now been projected that per capita surface water availability would fall to 1401 m^3 and 1191 m^3 by the years 2025 and 2050, respectively. The Per capita water availability in the year 2010 was 1588 m^3 against 5200 m^3 of the year 1951 in India implying a fall of more than 60% [37]. It is estimated that by the year 2025 this would drop below 1000 m^3 per person. Of the total available potential of nearly 1800 BCM in India, only about 700 BCM can be utilized effectively (Table 9).

Table 9: Water demand, supply and corresponding overall deficits in 2030

Aggregate total demand in 2030 in BCM	Demand growth per annum (%)	Estimated water supply in 2030 (BCM)	Aggregate gap % of demand
1,498	2.8	744	50

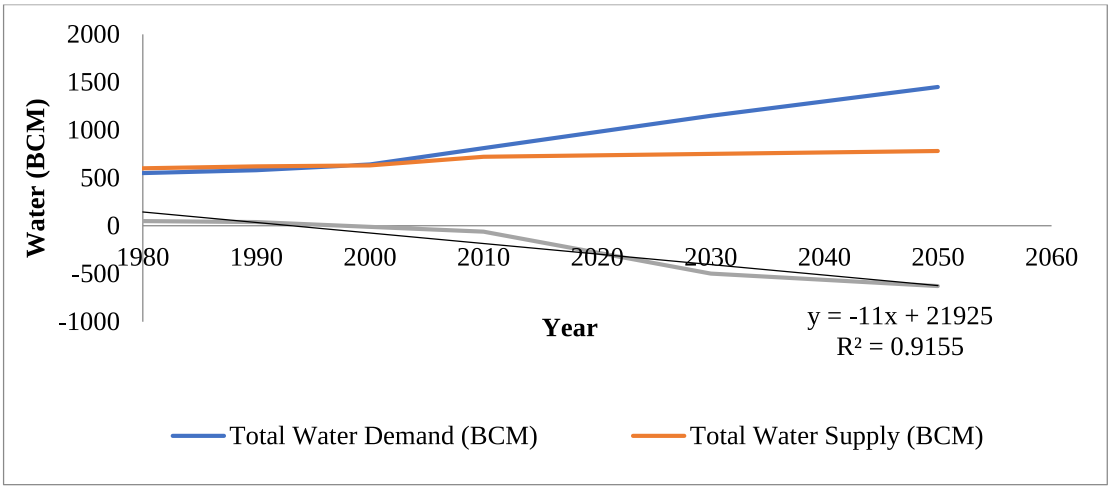
Source: IWMI 2000; Mall et al 2006; TERI 2017)

Water demand in India will grow to almost 1500 BCM driven by 2030 with domestic demand for growing more food grains like rice, wheat, and sugar for a growing population [16]. Against this demand, India's current water supply is approximately 740 BCM which is likely to remain stagnant and not show any increase (Table 10) [38].

Table 10: Water demand and supply- Past trend and future projections of water gap (BCM-Billion Cubic Meter)

Time Period	Total Water Demand (BCM)	Total Water Supply (BCM)	Deficit/Gap (BCM)
1980	550	600	+50
1990	580	620	+40
2000	640	630	-10
2010	813	720	-60
2030	1150	750	-500
2050	1450	780	-630

Source: Amarsinghe et al 2006, 2007; Gupta and Deshpande 2004; 2030 Water Resources Group



Source: Amarsinghe et al 2005, 2006; Gupta and Deshpande 2004; 2030 Water Resources Group

Fig. 4: Deficit gap analysis

The regression equation and a simple trend analysis give the following equation: $y = -11x + 21925$ $R^2 = 0.9155$, where y = water deficit (BCM) and x = time period. The deficit which is expected to be around -630 BCM in the year 2050 will further rise to -845 in the year 2070 and -1175 BCM in the year 2100. The deficit is expected to be spread unevenly across the country and the biggest brunt of the water shortages would be borne by north and central India where the variability in monsoon rainfall will hit the surface water availability very hard. Groundwater extraction has already reached a limit once an aquifer goes dry, it is impossible to revive the same by different methods of recharging.

11. CONCLUSIONS

Over 500 million farmers in India depend on agriculture for their living and nearly two-thirds of land under cultivation has no irrigation and is classified as rain-fed areas. Only 40% of the total cropped area is under irrigation by surface and groundwater resources. The water table is falling on average by 0.3 meters and by as much as 4 meters in rice growing areas of Punjab and Haryana. Water stressed and semi-arid regions are cultivating water intensive crops like rice and sugarcane. The problem is not lack of adequate water, but its reckless and inefficient overuse. Water efficiency rate is less than 35% in India indicating the magnitude of the problem. The future irrigation needs in agriculture which is still the largest employer in India would be dependent upon the extent of irrigated area, crop type, cropping intensity and irrigation water use efficiency.

An ambitious $150 billion river linking scheme for transferring water from surplus river system to deficit water areas and drought prone regions is under active consideration of the government. Rainwater harvesting and check dams' water conservation technique for capturing monsoon run-off can provide the country with reliable water supplies throughout the year. Most nations are using less than the fifth of total water received through rainfall and snow. The global average withdrawal of fresh water was only 9% of the water available for human use. Climate change has affected water in three ways. First, it has changed the way plants grows and reacts to increased levels of atmospheric greenhouse gases. Second, climate change increases problems of water management. Extreme events cause floods which are difficult to control and manage. Reservoirs do not store enough water for the entire year for proper planning for future. Third, climate change has led to rapid proliferation of production of biofuels in many countries. It takes up to 9000 litres of water to grow one litre of biodiesel. It takes at least three times as much water to grow maize in India as compared to China. In India it takes 1500 litres of water to produce a kilo of wheat and in some places only about 750 litres. Efficient irrigation practices can improve water efficiency by 30%, and this can be done if the water evaporates from the leaves of the plant, rather than from the soil.

Per capita domestic water use in 2050 in India is expected to be around 100 m^3/year which is inadequate by any standards. The rapid growth of population has reduced the per capita availability of fresh water from 3000 cubic metres to 1123 cubic metres over the past 50 years as against the global average of 6000 cubic metres. The demand supply deficit is expected to rise in the future. The demand in urban areas is around 140 litres per capita daily which is more than the daily rural demand of 40 litres per capita. Rapid urbanization and industrial development is expected to further strain the already existing water supply situation. Over 60% of the total irrigation requirement comes from groundwater and 30% of urban water supply and 70% of rural water supply comes from groundwater. India's supply of water is falling rapidly due to mismanagement of water resources and climate change is expected to exacerbate the problem by causing erratic and unpredictable weather, which would decrease the supply of water coming from rainfall and glaciers.

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