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Research Article

Climate Change Impact on Water Resources- An Overview

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ABSTRACT

Global climate change caused by increases in greenhouse gas concentrations is likely to increase temperatures, change precipitation patterns, and increase intensity of rainfall. These changes will affect hydrologic processes and water resources availability, and thereby affecting agricultural production and productivity. Simulation studies conducted using hydrological models with climate change projections from global climate models (GCMs) and regional climate models (RCMs) and different downscaling approaches have showed varied hydrological responses of different river basins to future climate change scenarios. Simulation using distributed hydrological model Precipitation Runoff Modelling Systems (PRMS) and GCM projected scenarios indicated an increase in the future annual streamflow in the Brahmani River basin for most of the climate change scenarios. Simulation results also showed that the effect of rising temperature on evapotranspiration demand is moderated by elevated CO_2 concentrations. A comprehensive understanding of adaptation options across the scenarios and regions, strategy of using indigenous coping mechanisms, adoption of existing technologies and further research and development efforts for evolving new technologies are necessary. The National Water Mission under the National Action Plan on Climate Change (NAPCC) is addressing the issues of water conservation and enhancing water efficiency and productivity. Similarly, the National Initiative on Climate Resilient Agriculture (NICRA), launched by the Indian Council of Agricultural Research, is providing the much needed impetus to climate change research in network mode through creation of state-of-the-art research facilities and demonstration of climate resilient practices through participatory approach in farmers' fields. Identification of vulnerable regions and prioritization of locally relevant adaptation options are essential for preparing adaptations strategies and its successful implementation.

Key words: Climate change, Global warming, Extreme events, Soil erosion, Carbon sequestration, Crop production.

Introduction

Land and water are the two most important finite natural resources for supporting livelihood and food security of burgeoning population of the country. Availability of freshwater water resources is of particular interest for supporting agrarian economy in a country like India. Per capita availability of water in India has declined sharply from 5177 m^3 in 1951 to 1544 m^3 in 2011 (CWC, 2013). It is projected a further reduction to 1465 m^3 and 1235 m^3 by 2025 and 2050, respectively (Kumar *et al.*, 2005). India has a seasonal rainfall pattern with nearly 75% occurring during the southwest monsoon (rainy) season. The year-to-year variability in monsoon rainfall often results in drought and floods like situation in many parts of the country, affecting agricultural production. Decline in grain yields of rice and wheat in the Indo-Gangetic Plains is partly due to change in weather conditions (Aggarwal *et al.*, 2004). The anticipated changes

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and variability in precipitation pattern and increase in air temperature will affect the regional water availability, and may further exacerbate the water scarcity condition.

The Fourth Assessment Report (AR4) of Intergovernmental Panel on Climate Change (IPCC) projected an area-average increase in the median annual mean temperature in the range of 2.5 (South East Asia) to 4.3 °C (Northern Asia) by the end of 21st Century (2080-2099) under A1b emission scenario (IPCC, 2007). Recent climate change projections (the Fifth Assessment Report-AR5), based on the Coupled Model Inter-comparison Project Phase 5 (CMIP5), projects a warming of 1.5, 2.4, 2.8 and 4.3 °C for India under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, in 2080s (2071-2100) compared to the baseline period of 1961-1990 (Chaturvedi *et al*., 2012). All-India mean annual temperature is likely to increase by 1.7-2.0 °C during 2030s and 2.0-4.8 °C during 2080s, relative to the pre-industrial base of 1880s (1861-1900). The precipitation may increase by 6-14% in 2080s. These changes have serious impacts on hydrologic processes and water resources availability, and thereby affecting agricultural production and productivity.

Climate Change Impact on Water Resources

Global climate change is expected to alter regional hydrological condition, affecting the water resources availability. With increase in total rainfall and high intensity rainfall events, occurrence of flood incidence is likely to increase under the changing climate scenarios. At the same time, increased evapotranspiration (ET) demand and/or decreased precipitation may result in severe and widespread drought by late half of this century (Dai, 2013). Sea level rise due to climate change is likely to increase the salinity problem along the coastal regions. The IPCC projection envisages change in water resources availability in most regions of the world. With doubling of the CO_2 concentration, global mean runoff may increase by 5% as a result of reduced ET due to CO_2 enrichment (Betts *et al.*, 2007). Simulation studies conducted on 12 river basins of India, using distributed hydrological model 'Soil and Water Assessment Tool (SWAT)' and HadRM2 regional climate model (RCM) projected scenarios, indicated a general reduction in runoff in the future (2041-2060) (Gosain *et al.*, 2006). However, when PRECIS (Providing Regional Climates for Impact Studies) RCM A1b emission scenario data was used along with the SWAT hydrological model, an increase in water yield was reported in most of the Indian River systems during 2030s and 2050s, except in the Pennar River basin, where decrease in water yield during 2030s was predicted (Gosain *et al.*, 2011). Islam *et al.* (2012a), while studying the impact of climate change on streamflow in the Brahmani River basin using the US Geological Survey's Precipitation Runoff Modelling System (PRMS), reported that the changes in temperature had lesser effect on the magnitude of annual and seasonal streamflow compared to rainfall changes in the basin. A 10% decrease in rainfall results in 23% decrease in annual streamflow, whereas 4°C rise in temperature may cause 11% decrease. The combined rainfall-temperature effect modifies the mean annual streamflow by -33 to 62%. A 4 °C rise in temperature coupled with 30% increase in rainfall results in 62, 73, 39, 52 and 30% increase in annual, monsoon, pre-monsoon, post-monsoon and winter season streamflow, respectively (Fig. 1). Similarly, a temperature rise of 4 °C and a 10% decrease in rainfall resulted in 33, 35, 15, 32, and 21% decrease in annual, monsoon, pre-monsoon, post-monsoon and winter season streamflow, respectively. Table 1 summarizes changes in water availability and hydrologic regimes in different river basins of India (Islam *et al.*, 2014).

Most of the Global Climate Models (GCMs) simulate reasonable average annual and seasonal features of present climate over large geographic areas, but are less reliable in simulating smaller spatial and temporal scale features that are relevant to regional impact assessment studies (Grotch and MacCarcken, 1991). Further, considerable uncertainty is associated with GCM simulations due to uncertainty in greenhouse gas (GHG) emissions, uncertainty in global GHG cycles usually simulated "offline", and

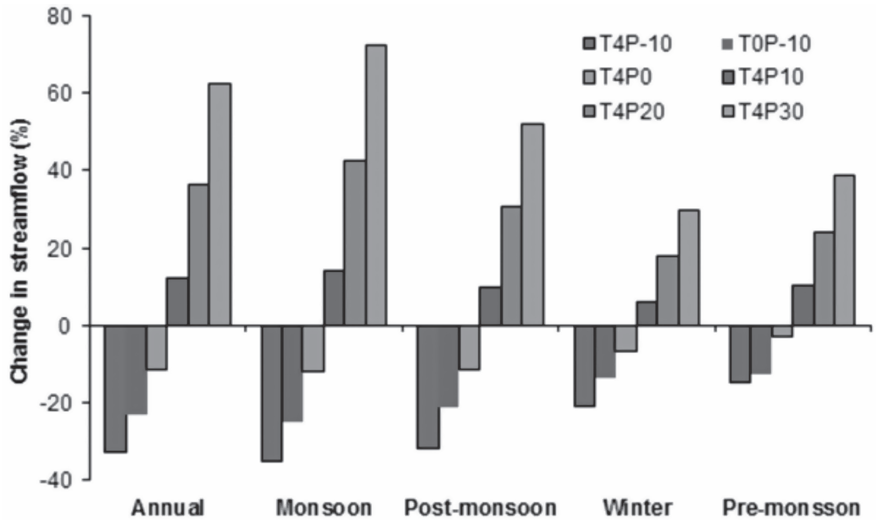


Fig. 1. Streamflow response to changes in rainfall and temperature

Table 1. Climate change impact hydrology and water resources in India

River basin	Impact
The Ganges basin	Increases in mean annual runoff in all sub-basins.
Spiti basin	Increase in temperature results in a large increase in streamflow during the pre-monsoon season followed by monsoon season. Under a warmer climate scenario, snowmelt runoff and glacier melt runoff cause an earlier response of total streamflow.
River basins of Central India	The Sher basin is more sensitive to climate change followed by Kolar and Damanaganga.
Kosi basin	A 2% to 8% decrease in runoff with 4 °C temperature rise and no change in precipitation.
Damodar River basin	Reduced water availability for the 2050s and 2060s scenarios.
Satluj River basin	Snowfed basins are more sensitive in terms of reduction in water availability.
River basins of India*	A general reduction in the quantity of the available runoff under the future (2041-2060) HadRM2 projected scenario.
Mahanadi River basin	A decreasing trend in future monsoon streamflow; and is expected to experience progressively increasing intensities of flood in September and drought in April.
River basins of India**	An increase in water yield in most of the Indian river systems during 2030s and 2050s under PRECIS RCM A1b projected scenario.
The Brahmaputra River	Increase in peak discharge and flood duration during pre-monsoonal and monsoonal seasons, but reduction in number of flood waves per season.
Tungabhadra river basin, India	Increase in average annual streamflow during 2020s, 2050s, and 2080s.
Brahmani River basin	Streamflow is more sensitive changes in rainfall as compared to temperature changes; and increase in annual as well as seasonal streamflow in the basin under projected climate change scenarios.
Kangsabati river catchment	Decrease in reservoir inflows.

* Brahmani, Cauvery, Ganga, Godavari, Krishna, Luni, Mahanadi, Mahi, Narmada, Pennar, Sabarmati, Tapi

** Baitarni, Brahmani, Brahmaputra, Cauvery, Ganga, Godavari, Indus, Krishna, Luni, Mahanadi, Mahi, Meghna, Narmada, Pennar, Sabarmati, Subernrekha, Tapi uncertainty in GCM response to a particular forcing associated with the model structure, parameterization, and spatial resolution (Andersson *et al.*, 2006). Hence, in order to address the uncertainty linked with climate projections, use of climate change scenarios from more than one GCM is suggested (Minville *et al.*, 2008; Maurer, 2007; Andersson *et al.*, 2006) as it provides a range of possible changes of future streamflow and water resources availability.

Simulation studies conducted using PRMS model with Third Assessment Report (TAR) projections from four different GCMs (CGCM2: Canadian Center for Climate Modeling and Analysis (CCCma), Canada; CSIRO-Mk2: Commonwealth Scientific and Industrial Research Organization, Australia; HADCM3: Hadley Centre for Climate Prediction and Research, UK; CCSR /NIES: Center for Climate System Research (CCSR) / National Institute for Environmental Studies (NIES), Japan) and two emission scenarios (A2 and B2) for different time horizons (2020s, 2050s and 2080s) showed increase in streamflow for most of the projected climate change scenarios (Fig. 2). However, magnitude of increase varied during different

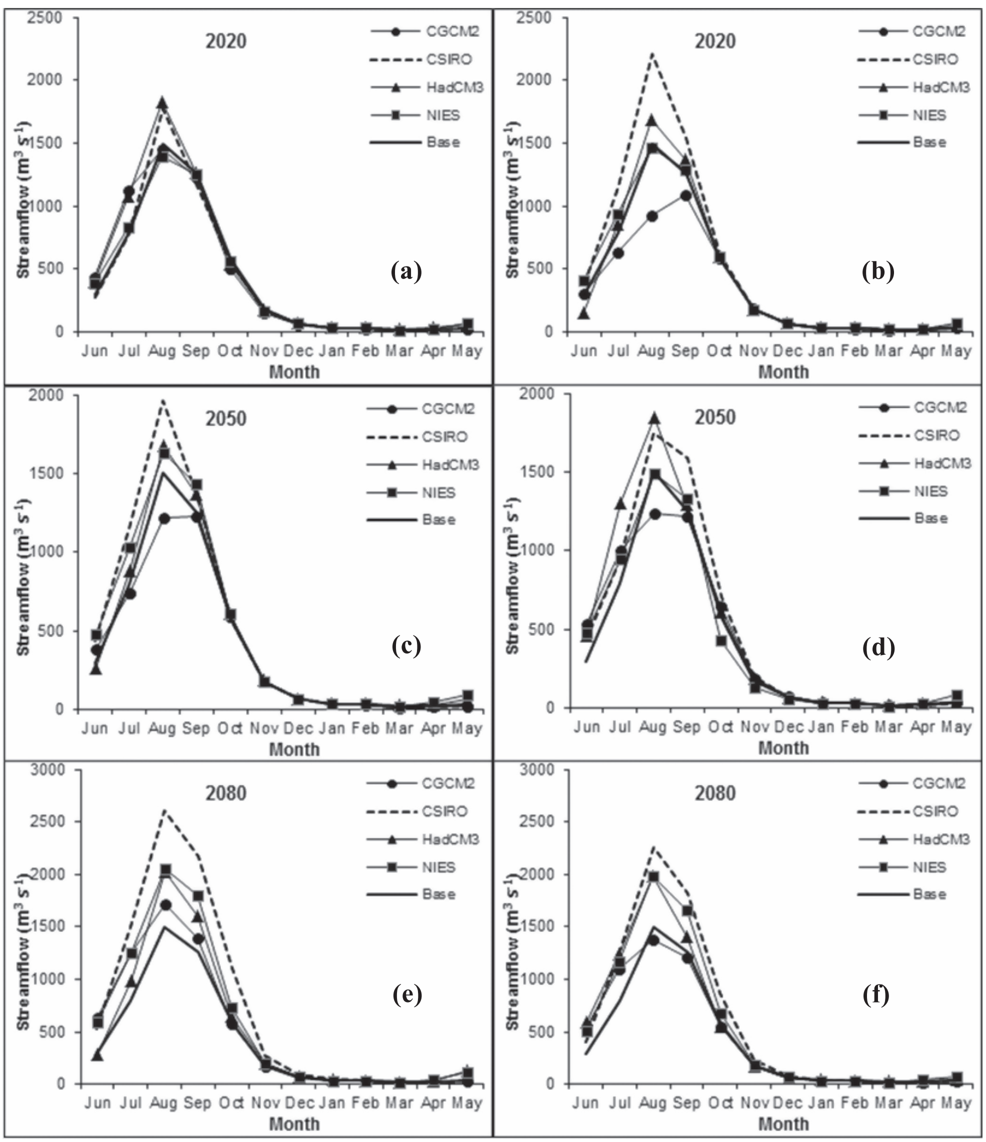


Fig. 2. Simulated annual (a, c and e) and seasonal (b, d and f) hydrographs under different climate change scenarios

months. The HADCM3 and CSIRO generated scenario resulted in increase in mean monthly streamflow in most of the months during all the time horizons. With changes in temperature and rainfall under the A2 scenario, the simulated streamflow in August could vary in the ranges of 1832.8 (HADCM3)-1390.5 m^3 s^{-1} (NIES), 1965.8 (CSIRO)-1121.8 m^3 s^{-1} (CGCM2), and 2603.3 (CSIRO)-1710.3 m^3 s^{-1} (CGCM2) during the 2020s, 2050s, and 2080s, respectively, as against baseline value of 1500.0 m^3 s^{-1}. In case of B2 scenario, the simulated streamflow in August varied in the range of 2206.2 (CSIRO) - 930.5 m^3 s^{-1} (CGCM2), 1850.6 (HADCM3) - 1239.6 m^3 s^{-1} (CGCM2), 2256.8 (CSIRO) - 1378.2 m^3 s^{-1} (CGCM2) during 2020s, 205s, and 2080s, respectively. The CGCM2 projected rainfall and temperature resulted in decrease of streamflow in most of the months during 2020s and 2050s under both the emission scenarios. This broad range of changes in streamflow is mainly caused by divergent projections for rainfall changes predicted by different GCMs, with no uniform trend was available during different periods.

An increase in annual streamflow (ASF) with all but CGCM2 climate change scenario is predicted (Table 2). In case of CGCM2, a 6% decrease in ASF during 2050s under A2 and 18% decrease during 2020s under B2 scenario were estimated. The change in ASF varied from -18 to 30, -6 to 23, and 7 to 75% during 2020s, 2050s and 2080s, respectively depending upon the GCMs and emission scenarios. Increase in ASF is the maximum under the CSIRO generated scenarios for all the time periods. The average (over GCMs) values indicated 6, 11 and 42% increase in ASF during 2020s, 2050s and 2080s, respectively under A2 scenario, and 6, 14 and 29% increase under B2 scenario. Increase in streamflow is also reported in monsoon (rainy) season under all scenarios. During monsoon, the increase is 13-49 and 7-39% under A2 and B2 scenarios, respectively. During pre-monsoon period, CGCM2 and CSIRO model predicts decrease in streamflow under A2 emission scenario in all three time horizons, whereas under B2 emission scenario, decrease is predicted during 2020s and 2080s. In the post-monsoon periods, most of the climate change scenarios resulted in decrease in streamflow during 2020s. During winter, changes in streamflow remain within ±10% in most of the cases. Maximum changes occur during pre-monsoon period, and variation is due to variation in changes in monthly rainfall.

Table 2. Changes (%) in annual and seasonal streamflow during different time horizons

Season	Period	HADCM3		CGCM2		NIES		CSIRO		All GCM	
		A2	B2	A2	B2	A2	B2	A2	B2	A2	B2
Annual	2020s	15	6	6	-18	1	7	2	30	6	6
	2050s	9	23	-6	5	18	5	22	21	11	14
	2080s	26	28	23	7	44	34	75	47	42	29
Monsoon	2020s	28	4	16	-28	0	9	9	44	13	7
(Jun-Aug)	2050s	9	39	-10	7	21	13	37	21	14	20
	2080s	27	47	39	17	50	41	79	52	49	39
Pre-monsoon	2020s	37	28	-14	-5	46	55	-26	-6	11	18
(Mar-May)	2050s	50	12	-22	5	107	71	-31	21	26	17
	2080s	131	30	-8	-10	113	77	-17	-18	55	20
Post-monsoon	2020s	-1	7	-6	-8	-1	3	-6	16	-3	4
(Sep-Nov)	2050s	7	4	-1	2	10	-5	5	24	6	6
	2080s	22	6	6	-4	35	25	77	45	35	18
Winter	2020s	2	6	-12	-3	2	1	2	2	-1	1
(Dec-Feb)	2050s	11	-2	-5	2	4	-13	4	10	3	-1
	2080s	5	3	-3	-8	-2	-1	29	18	7	3

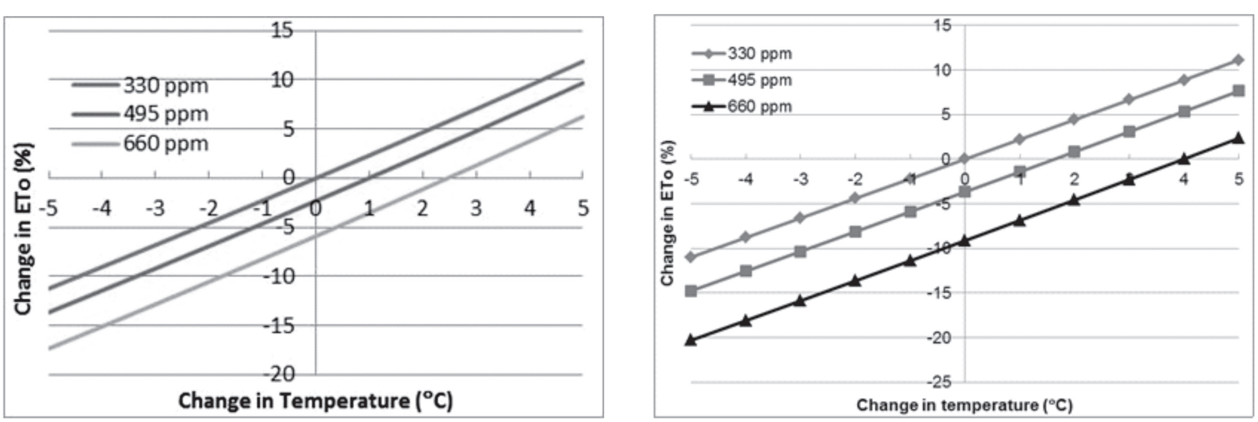
The temporal variability in the streamflow and availability of water resources in the basin under the influence of climate change suggests the need for development of different adaptation strategies, particularly for crop planning.

Climate Change Impact on Irrigation Water Demand

Irrigation water demand is likely to be affected due to changes in rainfall, temperature and the evaporative demand. The increase in temperature under the climate change scenarios is expected to increase the ET demand. As small as 1% increase in temperature could result in increase in the ET by 15 mm in arid Rajasthan, and thereby increasing the water requirement of 313.12 mcm for whole arid zone of Rajasthan (Goyal, 2004). Similarly, an increase in annual irrigation water requirements for paddy, sugarcane, permanent garden and semidry crops in the Bhadra reservoir command area has been projected using the MIROC 3.2 GCM climate projections under A1B emission scenario (Rehana and Mujumdar, 2012). This study also suggested that rainfall increase effect could be offset by the changes in other meteorological variables. However, there are studies indicating that the effect of rising temperature on ET is moderated by elevated CO_2 concentrations (Rosenberg *et al*., 1989; Islam *et al*., 2012b, 2012c), and thereby ET_o demand may not rise significantly. A simulation study demonstrated similar results in Varanasi (Priya *et al.*, 2014). They reported increase in ET_o by 0.1 mm d^{-1} (2.3% increase from baseline) annually with 1°C rise in mean temperature, and 6% decrease in annual ET_o demand with doubling (660 ppm) of CO_2 concentration while temperature remaining constant. Simulating the combined effect of temperature and elevated CO_2 resulted that 1.0 °C rise in temperature was offset by CO_2 increase up to 495 ppm, and 2.5 °C rise in temperature was offset by 660 ppm CO_2 level (Fig. 3). Similar results were reported for Akola also, wherein the effect of 1.7 and 4.0 °C rise in temperature on annual ETo is found to offset by increase in CO_2 levels by 495 and 660 ppm, respectively. This clearly indicates that simulation studies without consideration of CO_2 effects would result in overestimation of the drought effect and underestimation of the risk of flooding.

Adaptation Strategy

As climate change leads to water stress in several parts of the country, substantial adaptation efforts may ensure adequate supply and efficient utilization of available water resources. The supply and demand management measures aimed at conserving or improving the water supply may be capable to alleviate such impacts to a limited extent. The greatest potential for short-term adaptation is in demand-management and efficient and integrated management of surface and groundwater resources. Adoption of drip or



(a) Varanasi **(b) Akola**

Fig. 3. Effect of changes in temperature and CO_2 concentration on reference evapotranspiration

micro-irrigation, rainwater harvesting, groundwater recharge, water recycling, reducing loss in irrigation canal networks could be some of the major adaptation options. Participatory integrated watershed management approach covering biophysical and socio-economic interventions has greater potential in moisture conservation, attenuating peak discharge, controlling soil erosion, groundwater recharge etc., and has shown rich dividends at ensuring resilience to climate change.

National Programmes/ Policies

Since independence, a number of technological, institutional and policy/programme interventions have been implemented for increasing agricultural production and providing food security. From late 1960s onwards, the green revolution helped to maintain steady growth for more than two decades. Over the years, India has formulated National Agriculture Policy (2000), National Water Policy (2002, 2008 & 2012) and National Policy for Farmers (2007). For enhancing irrigation potential in the country, Ministry of Water Resources, Government of India, is implementing various programmes/ schemes viz. Accelerated Irrigation Benefits Programme (AIBP), Command Area Development and Water Management Programme (CADWM), National Project for Repair, Renovation and Restoration (RRR) of Water Bodies and Scheme on Artificial Recharge to Groundwater. Due to interventions under these Programmes/Schemes, area under rainfed agriculture has come down from 61% in 2000-01 to 55% in 2008-09.

A variety of agriculture development programmes/schemes have been initiated by different Ministries/Departments ranging from single component/commodity based sectoral scheme to area based integrated approach of watershed development. Rashtriya Krishi Vikas Yojana (RKVY), National Horticulture Mission (NHM), National Food Security Mission (NFSM), Rainfed Area Development Programme (RADP), National Mission on Micro Irrigation (NMMI), Accelerated Pulses Development Programme (APDP), Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM), Bringing Green Revolution in Eastern India (BGREI) are some of the important programmes for providing boost to agriculture sector. Besides, there are many schemes funded by the State Governments. Various Watershed Development Programmes are being implemented by Ministry of Agriculture and Ministry of Rural Development for development of rainfed areas and degraded lands including wastelands across the country. Due to interventions under these programmes, extent of wastelands has come down from 63.85 (1986-2000) to 55.27 Mha (2005) across the country.

Soil health related and oil seed and pulse promotion schemes of Ministry of Agriculture are other initiatives/schemes worth mentioning for management of natural resources and rainfed farming. The National Water Mission under the National Action Plan on Climate Change (NAPCC) addresses water conservation and enhancing efficiency and productivity of water besides sustainability of natural resources. National Initiative on Climate Resilient Agriculture (NICRA) is another major initiative by ICAR to address the impact of changing climate on agriculture and allied sector. The National Initiative on Climate Resilient Agriculture (NICRA), launched by ICAR in 2011, comprises of four components, namely, strategic research, participatory technology demonstrations in farmers' fields to cope with current climate variability, sponsored and competitive grants research to address critical research gaps in the area of climate change, and capacity building of stakeholders.

The technology demonstration component of NICRA envisages demonstration of climate adaptation and mitigation practices in vulnerable districts in a bottom-up approach. The focus of the programme is not only to demonstrate the climate resilient agriculture technologies but also to suggest institutional mechanism at the village level for continued adoption of such practices in sustainable manner. Different interventions like *in-situ* moisture conservation, biomass mulching, residue incorporation instead of burning, brown and green manuring, water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge and water saving irrigation methods has been implemented successfully to enhance resilience of Indian agriculture to climate change and climate variability. Options to address increasing water scarcity through better co-management of water at the watershed, aquifer and river basin level are needed in many water-stressed areas. The major challenge remains in proper planning and effective implementations of different developmental programs and schemes at the local level. Identification of vulnerable regions and vulnerable sectors is essential for prioritizing and implementation of adaptation plans. Decision support tools involving bottom-up participatory process for identifying locally relevant adaptation options and top-down integrated modelling approach will be helpful to identify, prioritize and assess the adaptation options for preparing adaptation strategies. .

Conclusions

Global climate change caused by increasing atmospheric concentration of carbon dioxide and other greenhouse gases is likely to raise the earth's mean temperature and change the precipitation pattern as well as the sea level. Changes in temperature and precipitation pattern under climate change and variability are likely to alter regional hydrological conditions, resulting in a wide variety of impacts on water resources systems. Extreme events like occurrence of flood and drought are expected to increase in future. Simulation results, using hydrological models with different GCM/RCM climate change projections and different downscaling approaches, have showed diverse hydrological responses of the Indian river basins. Although the increase in temperature will result in increased evapotranspiration demand, but the effect of rising temperature on ET is likely to be moderated by elevated CO_2 concentrations. Thus, crop water demand may not increase under changing climate scenarios due to moderating effect of elevated CO_2 concentrations on ET, increased precipitation as well as decrease in crop duration. The supply- and demand-management measures aimed at conserving the water supply may alleviate impacts of climate change to a limited extent in the water sector. Though several options are available for efficient utilization of scarce water resources, identification of vulnerable regions and sectors, and prioritization of different adaptation options are essential for successful implementation of adaptation plans.

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