

Increased arid and semi-arid areas in India with associated shifts during 1971-2004

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ABSTRACT

Climate change is one of the major challenges in 21st century faced by Agriculture in India, more so in the Semi-Arid Tropics (SAT) of the country. In recent years, natural and anthropogenic factors have impacted climate variability and contributed to a large extent to climate change. Based on one degree gridded data of India Meteorological Department (IMD) for 34 years (1971-2004), climatic water balances are computed for 351 pixels in India and used for classifying in to six climate types following Thornthwaite's moisture regime classification and areas falling under different climatic zones in India are delineated. Considerable changes in the country's climate area observed between the two periods; 1971-90 and 1991-2004. Increased semi-arid area by 8.45 M ha in five states viz., Madhya Pradesh, Bihar, Uttar Pradesh, Karnataka and Punjab, and decreased semi-arid area by 5 M ha in eleven states, contributed to overall increase in SAT area of 3.45 M ha in the country. Overall, there has been a net reduction of 10.71 M ha in the dry sub-humid area in the country. Results indicated that dryness and wetness are increasing in different parts of the country in the place of moderate climates existing earlier in these regions. ICRISAT's Hypothesis of Hope through Integrated Genetic and Natural Resources Management (IGNRM) using climate ready crops and Integrated Watershed Management could be a potential adaptation strategy by bridging the yield gaps for developing climate resilient agriculture in the country.

Key words : Climate change, semi-arid areas, gridded climate data

It is now recognized that global warming, part of the climate change phenomenon, is due to sharp increases in the concentration of greenhouse gases (GHG) such as carbon dioxide (CO₂), methane (CH₄), nitrous oxides (N₂O), chlorofluorocarbons (CFCs) beyond their natural levels. Indian Network of Climate Change Assessment (INCCA) brought out a report (INCCA, 2010) recording the GHG emission estimates in India, becoming the first "non-Annex I" (i.e., developing) country to publish such updated numbers. In 2007, India ranked 5th in aggregate GHG emissions in the world, behind USA, China, EU and Russia. Interestingly, the emissions of USA and China were almost 4 times that of India in 2007. It is also noteworthy that due to the efforts and policies that were proactively put in place, the emissions intensity of India's Gross Domestic Product (GDP) declined by more than 30% during the period 1994-2007. India announced its plan to further reduce the emissions intensity of its GDP by 20-25% between 2005 and 2020, even as the country pursues the path of inclusive growth (INCCA, 2010).

Climate change is an important driver affecting livelihoods, particularly in developing countries like India, with large agrarian-based livelihoods exist. In India,

climate change could exacerbate existing stress on ecological, natural resources and socioeconomic systems due to growing population, urbanization, industrialization and economic development.

Temperature, rainfall and evapotranspiration trends in India

Measurement of atmospheric turbidity (attenuation of incoming solar radiation) has shown a steady increase as a result of anthropogenic activities (DST, 2008). Indian annual mean (average of maximum and minimum), maximum and minimum temperatures showed significant warming trends of 0.51, 0.72 and 0.27°C 100 yr⁻¹, respectively, during the period 1901–2007 (Kothawale *et al.*, 2010). However, accelerated warming was observed in the period 1971–2007, mainly due to intense warming in the recent decade 1998–2007. Mean annual temperature of India in 2010 was +0.93°C above the 1961-1990 average and the India Meteorological Department (IMD) declared that 2010 was the warmest year on record since 1901 (IMD, 2010). Mean temperature in the pre-monsoon season (March-May) was 1.8°C above normal during the year 2010.

At the country level, no long-term trend in southwest monsoon rainfall was observed; although an increasing trend in intense rainfall events are reported. Goswami et al., (2006) analysed gridded rainfall data for the period 1951-2000 and found significant rising trends in the frequency and the magnitude of extreme rainfall events, and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. They concluded that a substantial increase in hazards related to heavy rainfall is expected over central India in the future. Increased frequency and intensity of extreme weather events in the past 15 years were also reported by Samra *et al.* (2003 and 2006).

Chattopadhyay and Hulme (1997) reported that potential evapotranspiration has decreased over the whole country in the monsoon and post-monsoon seasons and the decreasing trend is up to a maximum of about 0.3 mm day⁻¹ decade⁻¹ over west-central India. Trends in annual reference crop evapotranspiration (ET₀) at Patancheru, Andhra Pradesh indicated a reduction of about 200 mm from 1850 mm to 1650 mm during the 35-year period 1975-2009 (Rao and Wani, 2011). At Patancheru, contribution of energy balance term to the total ET₀ has shown an increasing trend while aerodynamic term has a decreasing trend. Wind speed has shown a strong negative trend leading to the dramatic fall of the aerodynamic term and consequently the ET₀. Rate of reduction in evapotranspiration demand was about 10% for *khari* (Jun-Oct) and about 14% for *rabi* (Nov-Feb).

It is evident from the various studies that climate change in India is real and it is one of the major challenges faced by Indian Agriculture, more so in the semi-arid tropics (SAT) of the country. India ranks first among the countries that practice rainfed agriculture in terms of both extent and value of production. The rainfed agro-ecologies cover about 60 per cent of the net sown area of 141 million ha and are widely distributed in the country (DOAC, 2011).

Rainfed agriculture is practiced under a wide variety of soil types, agro-climatic and rainfall conditions. Rainfed agriculture supports nearly 40% of India's estimated population of 1.21 billion in 2011 (Sharma, 2011). Even after achieving the full irrigation potential, nearly 50% of

the net cultivated area may remain dependent on rainfall. Reduction in yields due to climate change is likely to be more prominent in rainfed agriculture and under limited water availability. Thus, there is a need to review the areas falling under the different climate zones in India to understand the changing rainfall and temperature patterns over the last few decades. Accordingly, a study was carried out by ICRISAT to assess the changes in areas under different climates in India.

MATERIALS AND METHODS

Based on the daily rainfall data of 1803 stations, and following the interpolation method proposed by Shepard (1968), a high resolution (1° x 1° Lat/Long) gridded daily rainfall data set was developed by the IMD (Rajeevan et al., 2005). A daily gridded temperature data set for the Indian region with a similar resolution was also developed by IMD using temperature data of 395 quality controlled stations (Srivastava et al., 2009). These data sets were procured from the IMD, and daily gridded climate data (maximum temperature, minimum temperature and rainfall) of 351 pixels in India (Fig. 1) for 34 years (1971-2004) was retrieved.

The IMD daily gridded data originally was in binary format with 1120 pixels for each day in the geographical window of 6.5 to 37.5 °N latitude and from 66.5 to 100.5° E longitude for each calendar year. Binary data converted in to text format for each year; data for 351 pixels falling inside the Indian country boundary were picked out and correct latitude and longitude values assigned. These 34 yearly files were converted in to 351 pixel-wise files. It was observed that there were missing values in all the parameters; majority of them are in the NE India. Some are in the border regions of Jammu & Kashmir, Rajasthan and Gujarat. These gaps were either filled with neighbouring pixel values or normal values. After quality checking databases were developed for use in water balance computations and climate change analysis.

Potential Evapotranspiration (PET) or Reference Crop Evapotranspiration (ET₀) was estimated following the method of Hargreaves and Samani (1982 and 1985). The simplified equation is

$$ET_0 = 0.0135 (KT) (Ra) (TD)^{1/2} (TC+17.8)$$

Where TD = Maximum daily temperature minus minimum daily temperature (°C) for weekly or monthly periods and TC is the average daily temperature (°C); Ra = Extra-

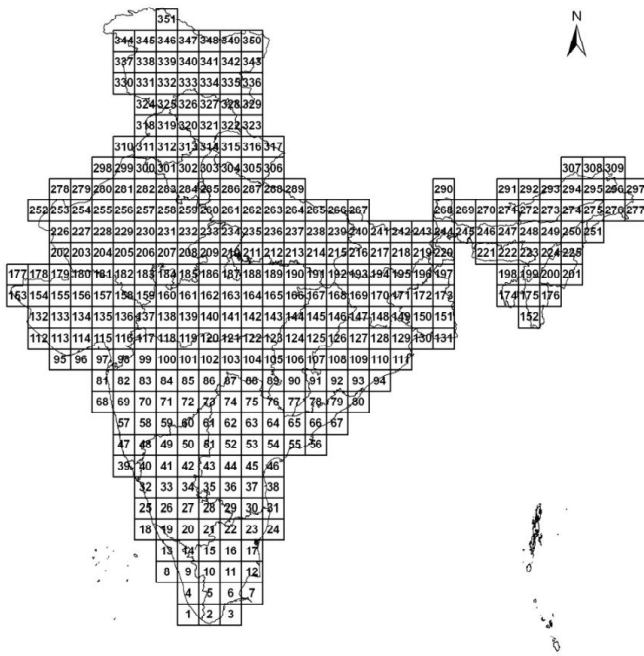


Fig. 1 : Location of 351 climate data pixels in India

terrestrial radiation (mm/day); and $KT =$ empirical coefficient. Relative humidity is indirectly present as the difference in maximum and minimum temperature. The temperature difference (TD) is linearly related to relative humidity (Hargreaves and Samani, 1982). Hargreaves (1994) recommended using $KT = 0.162$ for ‘interior’ regions and $KT = 0.19$ for ‘coastal’ regions. KT value is considered as 0.17 in the present analysis.

Soil water-holding capacities for the 351 pixels were estimated based on the soil map of National Bureau of Soil Survey & Land Use Planning (NBSS&LUP, 1985). Pixel-wise weekly water balances and climate indices for 34 years were computed based on the revised water budgeting approach of Thornthwaite and Mather (1955). Climates for each year were classified based on the annual moisture index (Table 1) as per classification of Thornthwaite and Mather (1955). While assessing climate change, it is an accepted method to find deviations from a base period. As per the WMO guidelines, 30-year continuous data is required to compute climatic normals. Standard periods for climatic normals are 1931-60 and 1961-90. In the present case, gridded data availability was 1971-2004, hence 1971-1990 is considered as the base period or period 1 and 1991-2004 is considered as period 2. Average climates classified into six types for both the periods 1 and 2.

Table 1: Climatic classification based on moisture index

Type	Moisture Index (Im)	Symbol
Per humid	100 and above	A
Humid	20-100	B
Moist Sub-humid	0-20	C ₂
Dry Sub-humid	-33.3 to 0	C ₁
Semi-arid	-66.6 to -33.3	D
Arid	Less than -66.6	E

Climate classification results of 351 pixels were converted to points and re-interpolated using ArcGIS 10.0 since a $1^\circ \times 1^\circ$ pixel is coarse and patchy to show the climate zones clearly. The Inverse Distance Weighted (IDW) method is used to interpolate the point data with an exponent of distance as 2 and the search radius fixed to 30 minutes and the number of points around the estimated value limited to 6. This was achieved after exploring different combinations of input variables which can be changed within the set limits. The resolution of the output grid is fixed at approximately 5 km. This method was used because IDW is an exact interpolator and estimated values do not cross the range of values in the total dataset. The area under each climate is the number of pixels multiplied by the area of each pixel which is fixed at 5 km. Minor aberrations in the area estimated and the area by conventional method was adjusted to remove ambiguity and state-wise areas under each climate were quantified for both periods.

RESULTS AND DISCUSSION

Considerable changes in climates are observed between the two periods, 1971-90 and 1991-2004. Salient features (Fig. 2) are increase in the arid areas in Rajasthan (1.53 M ha) and Gujarat (0.98 M ha), and increase in semi-arid areas in Madhya Pradesh (3.82 M ha), Bihar (2.66 M ha) and Uttar Pradesh (1.57 M ha).

Total increase in arid area is about 2.63 M ha in three states viz. Rajasthan (1.53 M ha), Gujarat (0.98 M ha) and Andhra Pradesh (0.12 M ha) while total reduction is about 1.03 M ha due to changes in Punjab (0.44 M ha), Karnataka (0.28 M ha), Haryana (0.16 M ha) and Maharashtra (0.15 M ha). For the country as a whole, net change in arid area is 1.60 M ha. Increase in the arid areas of Rajasthan and Gujarat is due to shifting of semi-arid areas in to arid.

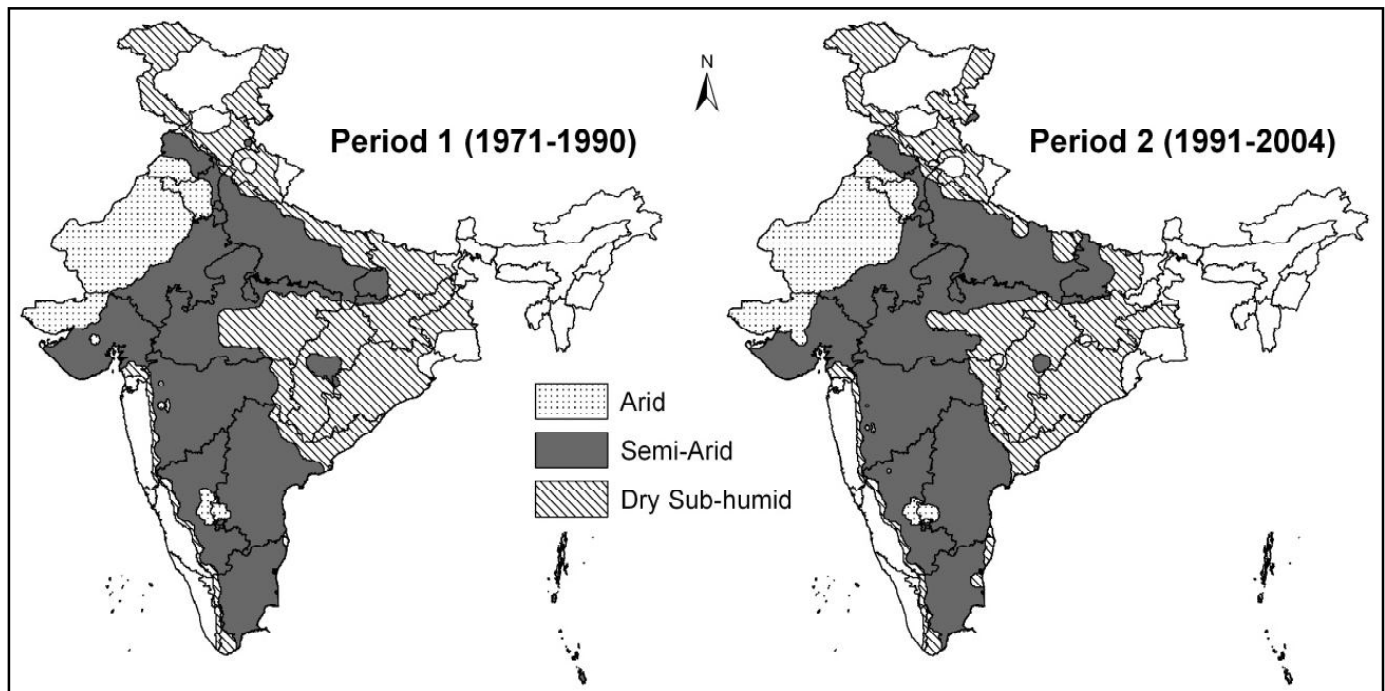


Fig. 2: Spatial distribution of dry climates in India during 1971-1990 and 1991-2004

Table 2: Areas under different climates in selected states in India

State	Period	Area in million ha						
		Arid	Semi-Arid	Dry Sub-humid	Moist Sub-humid	Humid	Per Humid	Total
Bihar	1971-90	0.00	1.82	6.88	0.39	0.32	0.01	9.42
	1991-04	0.00	4.48	3.39	1.04	0.47	0.04	9.42
	Difference	0.00	2.66	-3.49	0.65	0.15	0.03	0.00
Gujarat	1971-90	5.63	11.98	0.69	0.38	0.12	0.00	18.80
	1991-04	6.61	11.01	0.74	0.44	0.00	0.00	18.80
	Difference	0.98	-0.97	0.05	0.06	-0.12	0.00	0.00
Madhya Pradesh	1971-90	0.00	17.96	12.85	0.00	0.00	0.00	30.81
	1991-04	0.00	21.78	8.77	0.23	0.03	0.00	30.81
	Difference	0.00	3.82	-4.08	0.23	0.03	0.00	0.00
Rajasthan	1971-90	21.64	12.58	0.00	0.00	0.00	0.00	34.22
	1991-04	23.17	11.05	0.00	0.00	0.00	0.00	34.22
	Difference	1.53	-1.53	0.00	0.00	0.00	0.00	0.00
Uttar Pradesh	1971-90	0.00	18.09	5.54	0.00	0.00	0.00	23.63
	1991-04	0.00	19.66	3.96	0.01	0.00	0.00	23.63
	Difference	0.00	1.57	-1.58	0.01	0.00	0.00	0.00

Semi-arid area increased by 8.45 M ha in six states namely, Madhya Pradesh (3.82 M ha), Bihar (2.66 M ha), Uttar Pradesh (1.57 M ha), Karnataka (0.23 M ha) and Punjab (0.17 M ha) while total reduction is about 5 M ha due to negative changes in Rajasthan (1.53 M ha), Gujarat (0.97), Chhattisgarh (0.94 M ha), Tamil Nadu (0.90 M

ha), Andhra Pradesh (0.24 M ha), Orissa (0.16 M ha), Himachal Pradesh (0.15 M ha), Maharashtra (0.04 M ha), Haryana (0.03 M ha), Kerala (0.02 M ha) and Uttarakhand (0.02 M ha). For the country as a whole, net change in semi-arid area is 3.45 M ha. These changes are mainly due to increased dryness at the expense of dry sub-humid

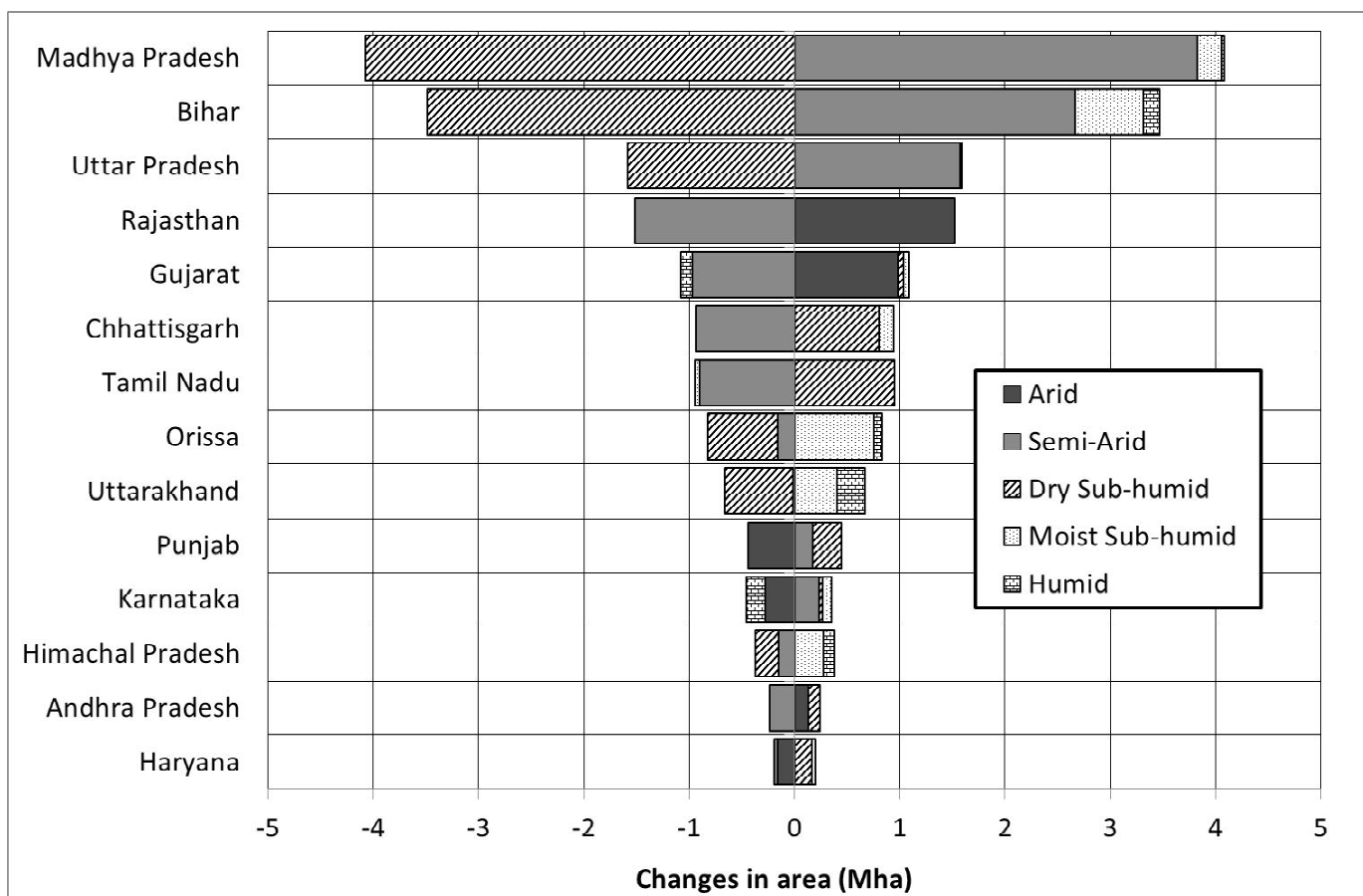


Fig. 3 : Changes in areas in selected states between 1971-1990 and 1991-2004

areas. Little increase in the Semi-arid areas in Karnataka and Punjab is due to decrease in the arid areas. Changes in areas under different climate types in selected states are presented in Fig. 3 and Table 2.

Total increase in dry sub humid area is about 2.51 M ha due to changes in Tamil Nadu, Chhattisgarh, Punjab, Haryana, Maharashtra, Andhra Pradesh, Gujarat and Karnataka while total reduction is about 13.22 M ha due to changes in Madhya Pradesh, Bihar, Uttar Pradesh, Jharkhand, West Bengal, Orissa, Uttarakhand, Himachal Pradesh and Kerala. Net change in dry sub humid area is 10.71 M ha, some of which shifted towards drier side and some towards wetter side. There is no change in dry sub-humid areas in Rajasthan. In the country as a whole, about 4.78 M ha of area has increased in moist sub-humid climate type while about 0.47 M ha area has decreased in per-humid climate.

ICRISAT's Hypothesis of Hope to address climate change

Climate change impacts in India vary both quantitatively and qualitatively by crop, level of agronomic management, region and season (Mall *et al.*, 2006).

ICRISAT's research findings showed that Integrated Genetic and Natural Resources Management (IGNRM) through participatory watershed management is the key for improving rural livelihoods in the SAT (Wani *et al.*, 2002, 2003 and 2011). Comprehensive Assessment (CA) of rainfed agriculture undertaken by the ICRISAT-led consortium showed vast potential of rainfed agriculture, as large yield gaps exist and current farmers' crop yields are lower by two to five folds of achievable yields (Rockström *et al.*, 2007 and 2010, Wani *et al.*, 2003, 2009 and 2011). Even under a climate change regime, crop yield gaps can still be significantly narrowed down with improved management practices and using Germplasm adapted for warmer temperatures (Wani *et al.*, 2003, 2009 and Cooper *et al.*, 2009). Some of the climate resilient crops are short-duration chickpea cultivars ICC 96029 (Super early), ICCV 2 (Extra-early) and KAK 2 (Early maturing); wilt resistant pigeonpea hybrid (ICPH 2671) with a potential to give 80% higher yields than traditional varieties developed through cytoplasmic male sterility (CMS) system; and short-duration groundnut cultivar ICGV 91114 that escapes terminal drought.

Integrated Watershed Management comprises improvement of land and water management, integrated nutrient management including application of micronutrients, improved varieties and integrated pest and disease management; and substantial productivity gains and economic returns by farmers (Wani *et al.*, 2003). The goal of watershed management is to improve livelihood security by mitigating the negative effects of climatic variability while protecting or enhancing the sustainability of the environment and the agricultural resource base. Greater resilience of crop income in Kothapally (Andhra Pradesh) during the drought year 2002 was indeed due to watershed interventions. While the share of crops in household income declined from 44% to 12% in the non-watershed project villages, crop income remained largely unchanged from 36% to 37% in the watershed village (Wani *et al.*, 2009). Agroclimatic analysis coupled with crop-simulation models, and better seasonal and medium duration weather forecasts, help build resilience to climate variability/change in watersheds (Rao *et al.*, 2008).

Sequestration of atmospheric carbon dioxide in the soil has the potential to achieve the multiple objectives of improving the soil quality and fertility of the semi-arid tropical soils and addressing climate variability/change. Evidence from a long-term experiment at ICRISAT-Patancheru since 1976 demonstrated a virtuous cycle of persistent yield increase under the improved system compared to the traditional system (Wani *et al.*, 2009 and Wani and Rockström, 2011). More importantly, under the improved system, the 0-120 cm soil profile contained 46.8 t C ha⁻¹ compared to 39.5 t C ha⁻¹ in the traditional management system. Hence, great scope exists for such improved systems for not only maintaining environmental quality but also addressing climate variability/ change as a mitigating measure. There is also an urgent need to develop a climate change network for Indian agriculture by adopting a hybrid model of using Information and Communication Technology (ICT) where it is feasible along with traditional communication channels like community radios, TV, mobile telephones and trained human resources at community and village level (Wani *et al.*, 2012). This will go a long way in building the resilience of the community to cope with the impacts of climate change, particularly in rainfed areas.

CONCLUSIONS

Analysis of the gridded climate data of IMD indicated increase in the arid areas in Rajasthan, Gujarat and Andhra Pradesh, and increase in semi-arid areas in Madhya Pradesh, Bihar, Uttar Pradesh, Karnataka and Punjab. Overall, there has been a net reduction in the dry sub-humid area (10.7 M ha) in the country, of which about 5.1 M ha (47%) shifted towards the drier side and about 5.6 M ha (53%) became wetter. Dryness and wetness are increasing in different parts of the country in the place of moderate climates existing earlier in these regions.

Results of the present analysis are based on one degree resolution data of IMD and the Inverse Distance Weighted (IDW) interpolation technique of GIS. Results may vary when better resolution climate data and other interpolation techniques are used. Methods of Hargreaves and Samani, and Thornthwaite and Mather could well estimate water balances based on gridded climate data and bring out the variability and changes in moisture regime climates in India.

Increasing dryness in the arid and semi-arid areas along with increasing rainfall variability is a serious challenge for Indian agriculture. Impacts of climate variability and change could be minimized/ coped through bridging the vast (two to three folds) gaps between the yields currently obtained by farmers and achievable potential yields. Evidence exists on feasibility of harnessing the untapped potential of rainfed agriculture through farmer-centric IWM approach by operationalizing the IGCRM. ICRISAT and partners have proposed the "Hypothesis of Hope" by developing climate resilient agriculture using climate ready crop cultivars and IWM approach as a powerful approach to adapt and mitigate the impacts of climate change. There is an urgent need to enhance the awareness about the climate change and new strategies using innovative science-based information and communication tools along with enabling policies and institutional options.

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