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NIAS Policy Brief

Climate Change and Indian Monsoon: Implications on Water Cycle

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The Question

Water is very vital for the survival of humanity and biota. One of the major implications of climate change is the modification of the spatial and temporal variability of monsoon rainfall, including an increase in extreme events. The light and moderate precipitation events are decreasing, and the heavy and extremely heavy rainfall events are increasing and likely to increase faster in the future. The other major change is the increase in mean rainfall over NW India during the last few decades, which is expected to rapidly increase in the future. The spatial and temporal changes in the monsoon occurring at monthly, seasonal, annual, and decadal scales have major implications on the water cycle and consequently on all water use sectors such as agriculture, power, biodiversity, urban settlements, etc. The questions are: what are the implications of changing monsoon patterns on the water cycle and whether we are prepared to adapt to these changes, which are likely to happen in the next 2-3 decades?

The Issue

The reliable and accurate information about the monsoon is critical for India as ~50 % people depend on agricultural related activities and contribute about ~17 % to GDP. Water availability per capita has been decreasing since 1950 due to an increasing population. The increase in extreme rainfall and decrease in low and moderate rainfall events are leading to changes in the water cycle. Flooding events are increasing, including in cities, and affect economic activities. The increasing number of extreme events will affect cities more severely.

It has been inferred based on instrumental records and paleo-climatic data that the Indian summer monsoon exhibits variability at sub-seasonal, seasonal, inter-annual, multidecadal and centennial time scales. For example, the Thar desert area had a flourishing civilization during the Indus Valley civilization (5300–3300 years BCE). The onset of the Meghalayan period (4200 years BCE), which is marked by a persistent drought (evidence from cave deposits in Meghalaya), probably led to the demise of this civilization.

The further increase in temperature and moisture is expected to lead to enhanced variability in mean, extremes, and inter-annual precipitation during the next few decades. The increased variability, especially in extreme events, is likely to lead to more intense flash-flood events, especially in the Indus, Ganga, and Brahmaputra basins. Elevated levels of the mean monsoon rainfall will lead to an increase in the frequency and intensity of large-scale flooding events as well. The increase in tropical cyclones will also lead to increased flooding in coastal areas.

The increased rainfall in the NW region due to the westward shift of the monsoon is likely to lead to the greening of the desert and eventually benefit agriculture. The increased flooding in the absence of efficient drainage will affect socio-economic conditions. At the same time, the Indus basin is likely to receive a reduced amount of snowfall, which may affect river flow during the summer months.

In view of such a scenario, it is necessary to understand and model how changes in rainfall patterns are going to affect the water cycle, especially shallow groundwater tables, urban settlements, etc. The changes in shallow groundwater are critical, as it supports terrestrial ecosystems and base flows in rivers. The changes in sea level and terrain conditions will also affect the water cycle. Understanding the impacts of changing monsoons on ecosystems, economic systems, human health, and the built environment is vital.

It is imperative that strategies for reduction of risk and improving the potential of hydrological and ecological systems to be self-sustaining, resilient, and adaptable to climate change and their impacts be developed. The future projections related to changes in monsoon patterns, droughts, sea level rise, ocean warming, cyclones, and Himalayan systems, to be translated into policy directions to strengthen the response to climate change. In this policy brief, the implications of a changing monsoon are discussed, and interventions are suggested.

The Findings

The key findings from the analysis are,

i) During the *historical period* (1901 and 2015), the mean rainfall during June-September over NE India decreased by 8% while that over NW India increased by 8%, while that over Central India (MP, Maharashtra, Jharkhand, Orissa, Telangana, and AP) remained almost unchanged from their base value (1901–1930 mean). The mean rainfall over India has increased by 3% during this time.

ii) During the historical period, the CMIP6 models overestimate the ensemble of frequencies of extreme rain events over NE India while underestimating it over Central and NW India. The change during the same period is underestimated by 50% over all three regions. The projected changes by the models are therefore underestimated by at least 50% (Table 1).

iii) It has been *projected* that the temperature over Central India is likely to rise between 1.5-1.8^{0}C by the 2050s and between 2.2-4.0^0 C by 2100s and mean precipitation between 11-13% by 2050s and 15-30% by 2100s (See Table-1). The ranges correspond to changes between SSP2 and SSP5. While the temperature changes averaged over NE India, Central India, and NW India are similar (see Table-1), the percentage changes of rainfall are different over NE and NW India compared to Central India. Increased greenhouse gas forcing primarily drives the westward expansion of the Indian monsoon rainfall. The recent flood events in Gujarat, Rajasthan, and Pakistan, and the increased frequency of extreme events in Central India in recent years are evidence of this increasing trend of rainfall.

iv) The number of extreme rainfall events is increasing in all three regions, with the largest rate over Central India going from 24 to 41 and the slowest over the Northwest going from 13 to 19. As ~20 cm/day (~ 45 cm/day) rain-events represent the 99.5 percentile over the Central India (NE India), a doubling of the number of extreme events (>99.5 percentile) means a four-fold increase in hydrological disaster potential over the NE India relative to that over the Central India. (see Table-2, Goswami et al., 2006. https://doi.org/10.1126/science.1132027, Zahan et al., 2021, https://doi.org/10.1007/s10584-021-02994-5)

v) As the seasonal rainfall is expected to increase by 4%, 13% and 16 % over NE, Central and NW India, respectively, by 2050 with year-to-year variations about the mean of at least 10% of the mean (Table 2), the frequency of large-scale ‘floods’ and ‘severe-floods’ are going to increase substantially in all three regions. Combining this information with the fact that the ‘extreme rain events’ are going to double, severe hydrological-disaster events are going to drastically increase across the country.

vi) The rainy season in NW India lasts around 50–70 days, while in NE India, it lasts about 150–160 days. The length of rainy days in NW India has increased in recent decades and is likely to continue to increase, leading to further expansion of the rainy season and a significant change in the seasonal mean rainfall (50-100%) (Rajesh a, 2023, https://arxiv.org/abs/2212.13711)

vii) With the rainy season extending from 60 to 90 days, it will open possibilities for new crops to grow in the region as well as expand the scope of both rain-fed and irrigated agriculture.

viii) It is expected that the snowfall in the Hindukush Himalayas will continue to decline, while the Karakoram Himalayas will experience increased winter snowfall due to enhanced western disturbances (Krishnan et al. 2020, https://library.oapen.org/handle/20.500.12657/39973). As snowfall acts as a freshwater storage, the reduction in snowfall and increased rain will affect water availability during the summer, especially in the Indus basin.

The Implications

The changes in precipitation will affect many ecosystem services, especially the availability of freshwater and agricultural productivity. The precipitation must be considered in terms of its intensity and frequency rather than its annual total, as these parameters influence the amount of water that percolates into the ground. Most of the water from heavy rainfall is lost as runoff and does not recharge groundwater.

The current slow increase in rainfall and extreme events may be manageable or even beneficial to agriculture. However, it is very likely that a faster increase in the frequency and intensity of extreme events can lead to major disasters affecting food production, infrastructure, and the loss of lives. The food and water shortages may have serious implications for the population. As an example, we have seen in recent years that most cities are unable to manage extreme rainfall events, as existing storm water infrastructure is unable to handle increased water flow due to changing rainfall patterns.

In north-west India, water available from the Indus basin provides water for food crops and sustaining human life. The Indus basin depends mainly on snow and ice melt for water, which is likely to change. As snowfall is likely to reduce in the future, the decreased water availability is likely to affect food production in irrigated areas of northwest India and Pakistan.

The monsoon has been shifting westward, with an increase of about 25 percent in rainfall over northwest India and about a 10 percent decrease in mean rainfall in the northeast. The westward shift of the monsoon will be able to arrest the desertification process and will have a positive impact on the socio-economic conditions of the NW region. The dataset on agricultural primary productivity for 2001–19 has been produced for India using biophysical and climatic variables (Gangopadhyay et al. 2022, https://doi.org/10.1038/s41597-022-01828-y). The data show an increase in agricultural primary productivity in the NW region, probably due to increased rainfall.

The economic impact could be measured in billions of rupees due to the loss of infrastructure, urban services, power, etc. but also on non-economic losses such as loss of lives, public health, displacement and migration, damage to cultural heritage sites, etc. A current response mechanism must be enhanced to minimise losses.

The Interventions

It is necessary to increase our efforts to help the country negate or deal with the impacts of the changing monsoon. The benefits of such adaptation will accrue locally and ultimately at the national level. The following interventions are required.

i) The future projections related to changes in monsoon patterns, droughts, sea level rise, ocean warming, cyclones, and Himalayan systems, to be further improved to strengthen the response to climate change.

ii) A climate information system and an early warning system for rainfall, snowfall, floods, droughts, and cyclones are to be enhanced. Such systems must be linked to understand the impact on human health (vector-borne and water-borne diseases. e.g., malaria, dengue, meningitis, cholera). In such information systems, especially the Flood and Drought Information System, hydrological (efficient water use) and socio-economic data (support for affected people) are to be included.

iii) India has state-of-the-art indigenous operational weather and climate forecast systems in place. In view of the looming hydrological disasters all over the country, a skillful "Integrated Operational Flood Forecasting System" needs to be put in place. 'Flood shelters' like cyclone shelters, are to be built in vulnerable regions.

iv) For water security of the country in coming decades, ground water recharge is critical. Efforts to reverse the decreasing trend of number of water bodies in the country need to be enhanced not only de-silting and rejuvenating old water bodies but also creating new water bodies all over the country. This would not only improve the groundwater but also create a flood resilient ecosystem.

v) The meteorological and climatic parameters (temperature, rainfall, sea level, frequency of floods, droughts, and cyclones), terrain characteristics (topography, land use),

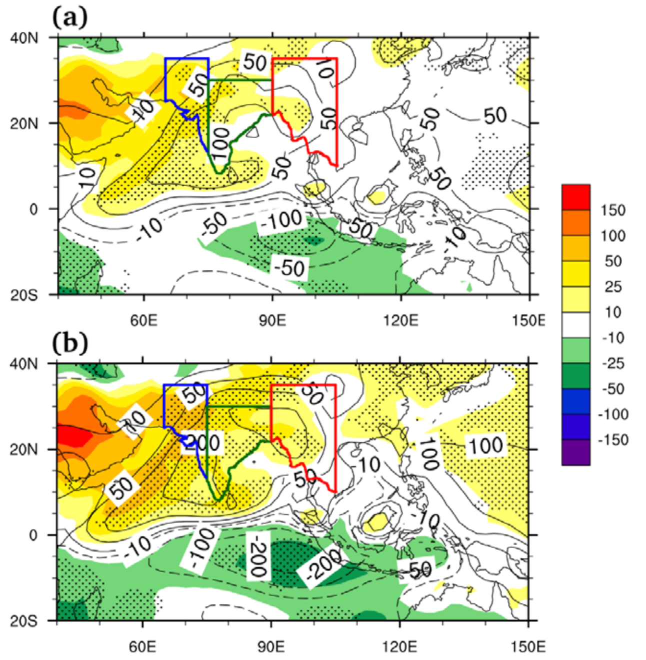
Table 1 Changes in mean seasonal rainfall and temperature (SSP2-4.5= Shared socio-economic Pathways, middle of the road; SSP5-8.5= Shared Socioeconomic Pathways, fossil-fuel-rich development)

		Observed changes in Monsoon rainfall/ Surface Temperature				Historical changes in Monsoon rainfall/ Surface Temperature				Projected changes in Monsoon rainfall /Surface Temperature (1901-2050)			
Parameter	Region (India)	Observed base value (1901-1930)		Observed Historical change (2014 - base value)		Simulated base value (1901-1930)		Simulated Historical change (2014 - base value)		SSP2-4.5 change (2050 - base value)		SSP5-8.5 change (2050 - base value)	
		mm	Interannual SD (%)	mm	%	mm	Interannual SD (%)	mm	%	mm	%	mm	%
Rainfall	NE	**1432.2**	**8.9**	**-110.4**	**-7.7**	**993.1**	**6.7**	**-21.5**	**-2.2**	**33.1**	**3.3**	**42.1**	**4.2**
	Central	**844.2**	**9.8**	**5.8**	**0.7**	**740.9**	**14.0**	**23.1**	**3.1**	**77.0**	**10.4**	**94.4**	**12.7**
	NW	**478.9**	**27.0**	**38.2**	**8.0**	**140.9**	**36.8**	**13.3**	**9.4**	**18.4**	**13.0**	**22.4**	**15.9**
Surface air temperature	NE	**-0.11**		**0.79**		**-0.20**		**0.52**		**2.01**		**2.51**	
	Central	**-0.35**		**0.63**		**-0.15**		**0.35**		**1.46**		**1.81**	
	NW	**-0.32**		**0.66**		**0.28**		**0.76**		**2.27**		**2.75**	

Table 2. Changes in the intensity of daily maximum summer monsoon rainfall and Frequency of occurrence above 99.5 percentile rainfall

		Observed changes in daily maximum rainfall amount			Historical changes in daily maximum rainfall amount			Projected changes in daily maximum rainfall amount (1901-2050)			
Parameter	Region (India)	Observed base value (1901-1930)	Observed Historical change (2014 – base value)		Simulated base value (1901-1930)	Simulated Historical change (2014 - base value)		SSP2-4.5 change (2050 – base value)		SSP5-8.5 change (2050 – base value)	
		mm	mm	%	mm	mm	%	mm	%	mm	%
Daily maximum rainfall amount	NE	**239.0**	**40.0**	**16.7**	**178.6**	**6.9**	**3.9**	**32.6**	**18.2**	**36.0**	**20.2**
	Centra	**236**	**48**	**20.2**	**185.6**	**10.8**	**5.8**	**42.6**	**23.0**	**51.2**	**27.6**
	NW	**171.0**	**36.0**	**21.1**	**95.2**	**14.3**	**15.0**	**30.7**	**32.3**	**33.4**	**35.1**
		Observed changes in frequency of occurrence above 99.5 percentile			Historical changes in frequency of occurrence above 99.5 percentile			Projected changes in frequency of occurrence above 99.5 percentile (1901-2050)			
Parameter	Region	count	count	%	count	count	%	count	%	count	%
Frequency of occurrence above 99.5 percentile	North East	**9.0**	**4.6**	**51.1**	**20**	**4**	**19**	**32**	**158**	**47**	**231**
	Core India	**24**	**17**	**70.8**	**11**	**3**	**31**	**12**	**106**	**17**	**154**
	North West	**13.0**	**6.0**	**46.2**	**9**	**2**	**24**	**9**	**95**	**11**	**118**

Fig. 1: Future changes of the South Asian Monsoon Rainfall



(a) The simulated changes in the CMIP6 Multi Model Ensemble (MME) rainfall amount (black contours), by subtracting the late pre-industrial climatology (1901–1930) respectively from the projected climatology at the end of the century (2070–2099) for the SSP2–4.5 ensemble and

(b) from projections at the end of the century for the SSP5-8.5 ensemble. The colour shading represents the percentage change (%) of rainfall amount with reference to the late pre-industrial climatology, and the contours represent the changes in seasonal accumulated rainfall amount (mm). The dotted area denotes the regions where the magnitude of the projected trend (MME mean change) to signal-to-noise ratio (SNR) (inter-model standard deviation) is greater than one. The NE, Core-India, and NW regions used for the analysis, shown in the above tables, are represented by the red, green, and blue polygons.

infrastructure and urban services (water supply and sewerage, storm water drainage, etc.), and socio-economic indicators (demography, slum population, urban sprawl) are to be integrated for resilient and sustainable cities.

vi) Strengthening of the observation networks of the atmosphere, hydrosphere, geosphere, cryosphere, and biosphere to increase our capability to generate outputs from predictive and empirical models to be planned.

vii) In view of the changing water cycle, a comprehensive accounting of the spatial and temporal availability of freshwater, both quantity and quality, for local and regional need needs to be developed. Such a system should assess the needs of humans as well as for the terrestrial ecosystem and biota.

viii) A strategy to address prediction of intense rainfall events must be worked out as well as how to harness these waters and allow them to percolate to the subsurface as groundwater reserves. An integrated plan by all concerned ministries, coordinated by the Ministry of Earth Science, is to be formulated, focusing on the reduction of risk and improving the potential of hydrological and ecological systems to be self-sustaining, resilient, and adaptable to climate change and its impacts.

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