In this issue

Climate change projections, impact and vulnerability assessment for India

Climate change is emerging as one of the most important environmental and developmental challenges of our time, with the potential to cause profound effects on ecosystems and society. It is now widely acknowledged that anthropogenic activities such as fossil-fuel emissions and deforestation are the primary drivers of climate change, and a portfolio of adaptation and mitigation actions are needed to diminish the risks associated with climate change.

Reliable information is required at national, state and district levels to assist policymakers, industry, climate-sensitive sectors and communities to mitigate and adapt to climate change. This special section brings out assessments of climate change and its impacts on crucial sectors such as agriculture, water resources, forests and health. This is a sequel and an update to an earlier special section on climate change that was published in *Current Science* in 2006.

Assessments of climate change and impacts at regional and local scales pose a huge challenge since the climate noise and hence the uncertainty is much larger at smaller spatial scales. Further, the climate models used in the assessments have coarser resolutions: general circulation models (GCMs) have a grid spacing of about 250 km and regional models about 50 km. The assessments reported in this special issue are derived from data generated by such models. Therefore, we caution that the assessments reported in this issue only provide a qualitative direction of impacts. Quantitative information is subjected to large uncertainty which needs to be assessed using multiple emission scenarios, and multiple global and regional climate models.

The regional model used in this study is Hadley Centre's model, PRECIS (Providing Regional Climates for Impact Studies). The regional climate simulations were performed at the Indian Institute of Tropical Meteorology (IITM), Pune.

First, Sharma and Chauhan (**page 308**) report on the government-level climate-change initiative, the Indian Network for Climate Change Assessment (INCCA) that was launched in October 2009. Under the aegis of INCCA, three assessments have been recently accomplished: (1) The report 'Greenhouse gas emissions of India for 2007 by sources and removal by sinks' was released in May 2010. (2) The assessment report 'Climate change and India: A 4×4 assessment – A sectoral and regional analysis for 2030' was released in November 2010. (3) The 'Black Carbon Research Initiative – Science Plan of the National Carbonaceous Aerosols Programme' was launched in March 2011.

Krishna Kumar *et al.* (**page 312**) examine the impact of global warming on Indian monsoon climate using PRECIS. They demonstrate first that the model exhibits reasonable skill in simulating the monsoon climate over India and then examine climate projections. The model projections indicate a large warming of about 4.5°C towards the end of the 21st century. The summer monsoon precipitation over India is expected to be 9–16% more in the 2080s compared to the baseline (1970s). The rainy days are also projected to be less frequent and more intense over central India.

Unnikrishnan *et al.* (**page 327**) analyse the winds and surface pressure fields from the regional model, PRECIS to study the change in cyclone statistics in the Bay of Bengal. They project an increase in frequency and intensity of cyclones during the late monsoon season in the future. However, the spatial pattern of composite tracks of cyclones does not show any appreciable change. The 100-year return levels of extreme sea-level events increase by about 15–20% by 2100 relative to the present day for locations north of Visakhapatnam.

Naresh Kumar *et al.* (**page 332**) make an assessment of impacts of climate change on major crops in the Western Ghats (WG), coastal districts and northeastern (NE) states using the crop model, InfoCrop. They find there would be winners and losers under climate change: yields of irrigated rice and potato in the NE region, rice in the eastern coastal regions and coconut in WG are likely to increase, whereas irrigated maize, wheat and mustard in NE and coastal regions, and rice, sorghum and maize in WG are projected to yield less. Therefore, the authors suggest adaptation strategies such as change in variety and altered agronomy.

Geethalakshmi *et al.* (**page 342**) study the impact of projected climate change on rice yields over the Cauvery basin, Tamil Nadu, using data from two regional climate models. They find that the simulated yields of ADT 43 rice could decrease by about 40% by 2100 when driven by climate-change data from one model, whereas the yield increases by about 8% when data are provided by another model. Their results indicate the huge uncertainty in predicting the impact of climate change on crop yields. The authors suggest specific adaptation strategies for economizing water and increasing the rice productivity under warmer climate.

Ranjith *et al.* (**page 348**) make an assessment of the impact of projected climate change on forest ecosystems in India using a dynamic vegetation model. They find that about 45% of the forested area in India is likely to undergo vegetation-type change. The mountainous forests are particularly susceptible to the adverse effects because climate change is predicted to be larger in higher elevations. They also find that forests in North East India are least vulnerable because rainfall is projected to increase there. These regional impact assessments

should assist in planning adaptation interventions in the forest sector.

Gosain *et al*. (**page 356**) quantify the possible impact of climate change on the water resources of Indian river systems using data from PRECIS. They use a hydrological model, SWAT (Soil and Water Assessment Tool) to simulate all the river basins of the country. Their main goal is to identify the vulnerable hotspots in view of the climate change in various parts of the country. The analysis is also performed on blue and green water so as to identify the impacts on these sub-components of water that are responsible for environmental functions and biomass production.

Diman *et al.* (**page 372**) use projection from PRECIS to assess malaria incidence under SRES A1B scenario for four regions: the Himalayas, NE, WG and the coastal regions. The authors find that Himalayan region is likely to open transmission windows in new districts with increase in 4–6 months category of transmission. In NE states, intensity of transmission is projected to increase from 7–9 months to 10–12 months. Western Ghats are projected to be affected minimally, while there is reduction in transmission months in the eastern coastal districts. The assessment provided by Diman *et al*. should help health managers to cope with the threat of climate change.

Ravindranath *et al.* (**page 384**) develop climate-change vulnerability profiles at the district level for agriculture, water and forest sectors for the North East region of India for the current and projected future climates. Their results indicate that majority of the districts in North East India are currently, subject to climate-induced vulnerability will do so in the future. This is the first such study that comes up with a ranking of districts of North East India on the basis of the vulnerability index values. Such ranking is useful in identifying and prioritizing the most vulnerable sectors and districts.

Naswa and Garg (**page 395**) present an interesting perspective on environment and infrastructure assets. Conventionally only the impacts of projects on the environment are studied. In this article, the authors highlight some crucial reverse impacts of environment on the energy, aviation, water supply and irrigation, road, communications, posts, health and housing, and railway infrastructure assets. These risks span beyond physical risks as strict mitigation regimes could jeopardize their profitability and even future existence. Therefore, the authors suggest that the key to manage risks lies in identifying them and initiating appropriate risk management and adaptation initiatives.

Finally, Sharma *et al*. (**page 405**) report on the greenhouse gas (GHG) emission inventory of anthropogenic origin from India for the year 2007 prepared under the aegis of INCCA. In 2007, emissions from India were of the order of 2000 Tg of CO_2 equivalents, excluding emissions from the land use, land-use change and forestry sector.

There has been significant progress in climate science in the past two decades, but there are still large uncertainties with respect to emission estimates, carbon sinks over land and oceans, climate projections and impact assessments. Following are some of the areas where there is scope for improving the impact assessments:

(1) The impact assessment studies in this special section have used only projections from a single GCM, namely HadCM3 and a single regional model, namely PRECIS. However, assessments of impacts of climate change should use results from multiple GCMs and regional models to assess the uncertainty and build confidence in the analysis.

(2) Multiple impact assessment models and tools could be employed to provide a range of impact projections for the same climate-change information for different sectors.

(3) Articles in this special section have made assessments for either the SRES A1B or A2 scenarios only. Exploration of other emission pathways (like A1F1, B1 and B2 scenarios) would provide a range of possibilities for the future.

(4) Typical resolution of today's regional climate models used climate projections is about 50 km. The accuracy of projections at the district level is expected to be higher at finer resolution, such as 10 km. Future work should attempt to use finer resolution data.

(5) Improvements in GHG inventory estimation should continue to be an important issue.

(6) Improved monitoring and documentation of observational evidence for climate change over India from terrestrial and marine ecosystems and Himalayan glaciers are needed.

India is a large developing country with nearly two-thirds of the population depending directly on the climate-sensitive sectors such as agriculture, fisheries and forests. Climate change is likely to have adverse impacts on coastal settlements, food production, freshwater supply, biodiversity and livelihoods. Thus, India has a large stake in developing a sound science base, and the technical capability to adopt and mitigate climate change.

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