

RESEARCH AND EDUCATION IN INDIA ON CLIMATE CHANGE

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India's wide-ranging ecosystems make its inhabitants vulnerable to climate change in many different ways. This article traces the educational opportunities and recent research in this field in Indian institutes and universities. Original research based in the country is critical for India's interest and well-being. But the research and knowledge base of this interdisciplinary field within India and its influence on policy making faces many challenges. There is a need for greater coordination and cross talk between different fields of research and education, government agencies and other stakeholders.

Introduction

Climate change is constituted by the long term changes in temperature, humidity, clouds, rainfall and similar weather factors¹. The 4th Assessment Report of the IPCC[†] (2007) stated² that the global mean temperature has increased by 0.74° C during the past 100 years. Scientifically, it has been proven that the average increase of global temperature is largely due to the anthropogenic (man-made) emission of greenhouse gases (GHGs) that include carbon dioxide, methane and oxides of nitrogen. The large increase reported cannot be ascribed to natural causes such as variations in the sun's energy output[#] or volcanic eruptions. Further, climate change is not just a global phenomenon, but can also be specific to a region, and regional climate change could be caused by both global and regional factors. The rapidly receding ground water level in highly populated river valleys of the world can be of concern for the food security of a large part of humanity. The loss of large tracts of rain forest cover globally each year can also harm the world in serious ways. Climate change for India is not just about rising temperatures due to global warming³, but also about changes in rainfall, melting of glaciers that feed our river

systems and rise in sea level. Even within India, the different regions are affected by different stresses brought about by combinations of the factors mentioned above. For example, J. Srinivasan points out that Gujarat and West Bengal are the states most vulnerable to sea level rise⁴. Developing countries like India suffer wide ranging effects on the environment as well as on economic and social factors, e.g., water resources, agriculture, food security, health, biodiversity, coastal economies and migration⁵ due to climate change.

Climate change is thus an area of concern not just for science, but touches upon all areas of human activities. Dipesh Chakrabarty⁶ notes that anthropogenic explanations of climate change have led to the obliteration of the distinction between Natural History and Human History. In other words, in one stroke, the idea of Anthropocene brings together fields as disparate as science, humanities and social science.

Navroz Dubash notes⁷ that despite the fact that climate change will (and is already starting to) affect a very large section of our population, it has been a political non-issue in India. It is "considered a distant foreign policy issue,

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† Intergovernmental Panel of Climate Change (IPCC)

For an account of the discovery of Global Warming, see "Changing Sun, Changing Climate?" at the website: <https://history.aip.org/climate/solar.htm>

the preserve of a few specialized diplomats and technocrats, and a handful of activists and academics.” Anu Jogesh⁸ notes however that the trends in climate change reportage in the Indian print media have been undergoing a moderate shift. Other commentators like D. Raghunandan⁹ have taken the position that poor understanding of the science, and geopolitical compulsions and tactics in India’s international negotiations has led to the detriment of global climate control.

In this context several questions may be relevant: (1) which higher educational and research institutions in India are carrying out significant research in science and policy; (2) whether our research and educational organizations are interdisciplinary in nature to include science, social sciences and humanities; (3) whether they are involved in shaping the national and international discourse or negotiations on climate change and (4) which particular areas of climate change research[‡] in the region may need to be enhanced.

This article provides an outline of the research and professional training on climate change in progress within India. The description here is only representative. The second section traces the efforts of a few research institutes under separate Ministries of the Government of India. The third and fourth sections deal with the efforts of a few educational institutions and the non-formal education sector in the role of human capacity building. The fifth section deals with non-governmental organizations working in policy fields. The sixth and the last section discusses the research and education scenario in the face of the challenges.

Research Organizations in India Working on Climate Change

The extent of involvement of Indian universities and research institutes in the area of climate change could be gauged from their publications in refereed journals. Nature Index[@] provides references[#] to specific areas of science in a region-wise basis for specific years and includes highly ranked journals[†]. The number of separate publications specifically on climate change that have at least one author with an Indian institutional affiliation, for the period July

2018 to June 2019, is 64. These articles were contributed by some 41 Indian institutions (note that under some categories, several institutions were clubbed together under a single heading, such as the separate IITs or the IISERs, or the different laboratories of CSIR engaged in research in this field). Also some of the papers were coauthored by several scientists from multiple Indian institutions. While the number of papers that scientists (co) author from a given institution varies from year to year, the largest chunk of these publications appears to come from the IITs, IISERs, Institutes associated with the Ministry of Earth Sciences, the Dept. of Space and CSIR, and the IISc. Universities associated with these papers were, among others, Delhi Univ., JNU, CUSAT, Pondicherry Univ., and Pune Univ.

Institutions of the Ministry of Earth Sciences

Centre for Climate Change Research, IITM, Pune : This centre (CCCR) was established in 2009 at the Indian Institute of Tropical Meteorology (IITM), Pune. An important focus of CCCR is to build human capacity in India to address the science of climate change, including the development of earth system models, development of future climate projections required for National Climate Change Assessment Reports, IPCC Reports and others, long-term observational monitoring of climate change, training, outreach and educational activities. Its work includes, assessment of climate change on the Indian monsoon, India’s water resources, and agriculture. Apart from a strong group with many scientists working on monsoon dynamics, the CCCR has research activities on global and regional climate modeling, physical oceanography, ocean atmosphere interaction, paleo-oceanography, and daily weather extremes. They use chemical and isotopic tracers to study the hydrologic cycle. It also has a web-based Climate Data Portal designed to facilitate the dissemination of climate information. Significant research publications from IITM during the last year (2018-2019) include “Rapid drying of northeast India in the last three decades: Climate change or natural variability?”¹⁰

[‡] Note that the IPCC does not carry out new research, but assesses published, peer-reviewed scientific literature and data relevant to the field and tries to arrive at a consensus of the climate trends.

[@] <https://www.natureindex.com/institution-outputs/generate/Earth%20&%20Environmental%20Sciences/countries-India/All/score>

[#] Nature Index site cautions “the data behind the tables are based on a relatively small proportion of total research papers, (and) that they cover the natural sciences only”

[†] These papers were published in: Geophysical Research Letters, Journal of Geophysical Research: Atmospheres, Environmental Science & Technology, Nature, Nature Geoscience, Nature Communications, Science, Proceedings of the National Academy of Sciences (USA), Geochimica et Cosmochimica Acta, Water Research, etc.

Institutions of the Department of Space

The Department of Space through the Indian Space Research Organisation (ISRO) runs the Indian Earth Observation System (EOS) that has a constellation of earth orbiting satellites. These satellites provide a wide and simultaneous view of the earth below in multiple colors including that of the atmosphere and the weather. Space based remote sensing (RS) not only helps in mapping earth resources and conditions, but can monitor changes in time and derive bio-geophysical parameters over a wide swath of the earth. These can be used in identifying the indicators and agents of climate change. With this input into the simulation models, prediction of the impact of climate change can be made, which in turn can help in planning adaptation measures[†].

The Programme on Climate change Research In Terrestrial environment (PRACRITI) under the Satellite Applications Centre/ ISRO (Ahmedabad) undertakes climate change/ climate based modelling and characterization studies of habitats from Indian coral reefs and mangrove swamps to high altitude Himalayan alpine ecosystems. They also study the impact of climate change over rivers basins of India, and snow melt from the Indian Himalayan regions. A review article¹¹ gives several examples of the use of space-based facilities and observations on climate change studies in the Indian context.

Indian Institute of Remote Sensing (IIRS), Dehradun : IIRS is an Institute under ISRO for capacity building in geospatial technology and its applications through training, education and research in the countries of Asia-Pacific. As such, its connection to climate change research is through its various Departments under the Earth Resource and System Studies Group, mainly the Marine and Atmospheric Sciences Department (MASD). Specifically, the Department provides research and development opportunities and user services in sea level rise and salt water intrusion into coastal aquifers; modelling estuarine and coastal processes; satellite oceanography and meteorology; Indian summer monsoon studies, climate modelling and extreme rainfall events. This Department has projects and publications of interest for coastal regions of India¹²⁻¹⁶. The Institute offers an M.Tech. course in Remote Sensing and Geographical Information Systems with specialization in 'Marine and Atmospheric Sciences' (2 years), apart from shorter PG Diploma courses.

[†] <https://www.sac.gov.in/Vyom/envandclimate.jsp>

Institutions of the Ministry of Environment, Forests and Climate Change (MoEFCC)

Ecologists and conservation biologists are now increasingly using remote sensing in forestry and ecological research to prepare for environmental change and appropriate response. Remote sensing technologies can potentially detect, identify and map forest canopy changes that are important for forest ecosystem planning, monitoring and management. Applications of RS in forestry and eco-resources include identifying the characteristics of plant species, spatial variability of species richness and detecting natural and anthropogenic changes in properties from regional to global scales (see Moni Devi et al¹⁷ and references therein).

Indian Institute of Forest Management, Bhopal : The Indian Institute of Forest Management (IIFM) at Bhopal was established in the 1980s. It has research activities on climate change, forestry, livelihood support and forest hydrology. It uses geospatial technologies to visualize problems. Research publications during 2016-17 included: Cyclone risk management and institutional accountability in eastern Odisha¹⁸; Rural development program in tribal region: adaptation and addressing climate change vulnerability¹⁹, etc. The active or past projects include: dynamics of climate change vulnerability in Sikkim (Jigyasa Bisaria (PI) 2017-18); a psychosocial study of risk perceptions, distress and coping strategies in cyclone affected districts of Odisha (Parul Rishi 2016-17); indigenous knowledge in practice: confirmation of climate change and its effects through practitioners' knowledge related to agriculture (G.A. Kinhal, D Dugaya 2015-16).

On training and education, IIFM recruited its 2017-2019 batch of students for Postgraduate Diploma for Forest Management (PGDFM) from diverse educational backgrounds, e.g. engineering, commerce, management & arts, science and planning. It also had a mix of students with prior work experience (42% had up to 4 years) and fresh graduates of various streams. All graduates of this batch, 90 in all, were placed, including 21 students in various government agencies. IIFM also has MPhil/ PhD programs, the latter in collaboration with the Forest Research Institute, Dehradun.

Institutions of the Council of Scientific and Industrial Research (CSIR)

A number of Institutes in the CSIR establishment list their interests in climate change and related research. The principal ones include: National Institute of Oceanography

(CSIR-NIO), Goa; Fourth Paradigm Institute (CSIR-4PI), Bangalore; National Geophysical Research Institute (CSIR-NGRI), Hyderabad; National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur. NEERI is involved in a case study of the Indo-Gangetic Plain for understanding synergies between climate change and environmental pollution, in Uttarakhand, for studying perturbations in Environmental Water Demand.

National Institute of Oceanography, Goa : The National Institute of Oceanography (NIO) having its headquarters at Dona Paula, Goa, was established in 1966. Apart from well-equipped laboratories at its headquarters, the NIO operates two research vessels for oceanographic observations: RV Sindhu Sankalp (56 m) and RV Sindhu Sadhana (80 m). With some 108 scientists at post-PhD level it has the largest number of oceanographic scientists working in an Indian institution. Its major areas of research include the four traditional branches of oceanography as well as ocean engineering, marine instrumentation and marine archaeology. Some 23 of its scientific and technical staff describe climate change as one of their research interests, with biogeochemistry as the most cited collateral interest, followed by air-sea interactions. NIO is a recognized centre for doctoral research by a large number of Indian universities. There are typically over 100 Junior/Senior Research Fellows pursuing their doctoral studies in the institute. In addition, about 300 undergraduate and postgraduate students pursue their project research here every year. It collaborates nationally with many Indian universities and research organizations. Internationally it collaborates with a number of institutions/ agencies in France, Japan, Bangladesh, Qatar and Mauritius.

NIO works on the tropical cyclones in the Bay of Bengal that are amongst the most lethal globally. These extreme events occur mostly in April–May and October–December before and after the Indian summer monsoon. NIO scientists urge that air-sea coupling that contributes to the Bay of Bengal cyclone intensity should be accounted for in operational forecasts²⁰.

Institutions of the Dept. of Atomic Energy

Tata Institute of Fundamental Research (TIFR) : To discern the role of the Bay of Bengal in the Indian monsoon for better predictability, a group at ICTS, TIFR, Bangalore has investigated the mixing of low-salinity water from the Brahmaputra-Ganga-Meghna delta with saline seawater of the Bay due to turbulence in its upper layers (above 25 m depth). The rain fed freshwater discharge from

the river systems into the northern part of the Bay provides a shallow layer in the Bay for 3-5 months starting around July. The upper layers have different mixing characteristics during summer and winter monsoons and their transition periods. The suppression of turbulent mixing during the transition periods leads to the maintenance of low salinity surface waters within the bay and affects the upper layers of the northern Indian Ocean for the next year's monsoon²¹.

TIFR Centre for Interdisciplinary Sciences at Hyderabad as part of its Community Outreach on Climate Challenge has put out some project ideas for students from the middle school to undergraduate levels (age range 12-20 years). Participants looked at questions like: Why does climate change matter? What are the local actions on climate change? What are the impacts of climate change on extreme weather like heat and cold waves or other extreme events? etc. They can consider how climate change appears from the perspective of an Indian farmer, the debate between developing and developed countries on climate action, and whether large-scale migrations escaping violent conflicts could increase under climate change²².

During 1993-96 the Homi Bhabha Centre for Science Education, TIFR conducted a project of talent nurture among post-school students in the arts, commerce and science streams which led to an Activity Based Foundation Course on Science, Technology and Society. An objective was to “integrate students’ curricular knowledge with environmental and developmental issues of concern, thus giving a broad exposure to several disciplines”. The subjects comprised many themes, and a series of books[±] were published by HBCSE. The programs were conceived and planned by the staff of HBCSE and conducted among selected students at secondary and higher secondary levels from urban and semi rural settings. Curriculum Book-5 focussed on Global Climate Change²³ with three global concerns: global warming, stratospheric ozone depletion and environmental destruction by acid rain.

Climate Change Education and Research Training in India

Indian Institute of Science Education & Research (IISERs) : The IISERs at Pune, Kolkata and Mohali have disciplinary areas or centres on Earth and Climate Science.

IISER Pune, designated as the National Resource Centre on Climate Change by the Govt of India, has introduced an online course[@] for higher education faculty for teaching climate change at the undergraduate level²⁴

[±] <http://www.hbcse.tifr.res.in/research-development/curriculum-material-development/foundation-curriculum>

[@] https://swayam.gov.in/nd2_arp19_ap55/preview

through the SWAYAM platform. The MHRD and UGC treat this online refresher course as equivalent to a regular face-to-face refresher course under the Career Advancement Scheme (CAS) of the UGC.

The course provides teacher training in all disciplines in the use of new pedagogical methods to introduce climate-change related content in their classrooms while teaching their discipline-specific topics. That is, instead of making climate change as a standalone topic, the course integrates climate science with the core curriculum of undergraduate and high school (Junior College) levels. In the area of societal impacts of climate change its modules deal with topics as diverse as climate refugees, environmental migration, climate justice, climate change and behaviour, climate change and children, food security, human health and disease, etc. It also gives teaching tools on water security, agro-ecosystems, food production and crop yields, climate resilient agriculture, and energy.

Academics at IISER Pune are involved in research on Himalayan glaciers, climate dynamics, monsoons, tropical ocean and atmospheric coupled processes, etc. Publications from their recent research include: Gridded emissions (of greenhouse gases, non-methane volatile organic compounds and particulate matter) from open municipal waste burning in India²⁵; Thinning of debris-covered and debris-free glaciers in a warming climate²⁶.

At IISER Kolkata, researchers in the Department of Earth Sciences work on paleobiology, river response to climate change, atmospheric black carbon and other optically active aerosol species, etc. A publication of their paleobiological research is: Predation to climate change: what does a fossil shell tell us?²⁷

IISER Mohali Faculty members have research interests in paleoclimate, aerosols and rainfall, resource recovery from wastewaters, CO₂ conversion to biochemicals and biofuels, and bioremediation of pollutants.

Indian Institute of Technology (IITs) : Several of the older IITs, and a few newer ones are involved in research on climate change and atmospheric science.

IIT Bombay has an Interdisciplinary program (IDP) for research and education on climate studies. The program has over 30 faculty participants drawn from 12 departments, across IIT Bombay, with expertise in climate science, technology assessment and policy.

The IDP doctoral program has core courses in two broad tracks of climate science and climate policy. In the area of science, the interests of the faculty members include: Indian monsoon, clouds and aerosols, ocean dynamics,

water resources engineering and water quality management, remote sensing, sustainability and environmental impact assessment, etc. In the area of policy, the faculty interests include: energy, water, vulnerability and adaptation and corporate sustainability. Examples of their work and publication in the past two years include: Improving global forecast system of extreme precipitation events with regional statistical model²⁸; An improved prediction of Indian summer monsoon onset from state-of-the-art dynamic model using physics-guided data-driven approach²⁹; Water–food–energy nexus with changing agricultural scenarios in India during recent decades³⁰. IITB (DESE) researchers have participated in a study of: Life cycle greenhouse gas impacts of coal and imported gas-based power generation in the Indian context³¹.

The IDP on climate studies has an ongoing sponsored project: Extended range hydro-meteorological forecasts for West Bengal at a district level, funded by Dept. of Environment, Govt. of West Bengal. The program recruits PhD/Junior Research Fellows as well as Postdocs in climate change.

At IIT Kharagpur, the Centre for Oceans, Rivers and Land Sciences (CORAL) offers advanced training in Earth System Science and Technology through a two-year postgraduate program, i.e. M. Tech. in Earth System Science and Technology and MS/PhD programs. Its research areas include climate change and climate modelling, Indian monsoon rainfall, extreme events, land use and land cover dynamics, marine geosciences, remote sensing, water masses and climate variations.

The oceanography group models tropical cyclone activity of the north Indian Ocean, ocean dynamics and ocean circulation modeling of the Bay of Bengal. Research publications include: Unusual premonsoon Eddy and Kelvin wave activities in the Bay of Bengal during Indian summer monsoon deficit³²; Assessment of urbanization and urban heat island intensities using Landsat imageries during 2000-2018 over a sub-tropical Indian city³³.

IIT Delhi, Centre for Atmospheric Science (CAS) researchers published a paper: Indian annual ambient air quality standard is achievable by completely mitigating emissions from household sources³⁴.

IIT Kanpur and IIT Delhi(CAS) researchers together with those from Centre for Earth, Ocean and Atmospheric Sciences, University of Hyderabad published a paper on: Aerosol-induced intensification of cooling effect of clouds during the Indian summer monsoon³⁵, while IIT Gandhinagar researchers have published an article on Drought and famine in India 1870-2016³⁶ and Increase in

subdaily precipitation extremes in India under 1.5 and 2.0 °C warming worlds³⁷ and Strong influence of irrigation on water budget and land surface temperature in Indian subcontinental river basins³⁸. IIT Bhubaneswar (School of Earth, Ocean and Climate Sciences) researchers have published a study on: Seasonal evolution of oceanic upper layer processes in the northern Bay of Bengal following a single Argo float³⁹.

Indian Institute of Science (IISc), Bangalore : The Divecha Centre for Climate Change (DCCC) at IISc conducts research on glaciology, aerosols, climate modeling, monsoon and biodiversity and policy. In the past, several separate departments at IISc conducted research related to climate change. In 2009 they came together to establish a coordinated activity through the Divecha Centre. One of its objectives is to connect their research with policy objectives. Many of their research programs revolve around tropical climate and understanding the monsoon and its variability and in the atmosphere-ocean climate sciences. These include atmosphere-ocean coupled general circulation and climate modeling, cloud physics, physical chemical and biological oceanography of the Indian Ocean, satellite meteorology, tropical convection and paleoclimate studies. They also have conducted studies on renewable energy, climate change economics, etc. Together with IIT-Guwahati and-Mandi, IISc has developed a climate change vulnerability assessment for the Indian Himalayan region⁴⁰. These assessments are relevant to many north and north-Indian states including Sikkim and the hill districts of West Bengal. Their research on aerosols and its impacts is pursued through multi-platform observational studies, involving high altitude balloon flights, aircrafts, etc.

The faculty associated with the Divecha Centre, their-postdoctoral researchers and students, comprise nearly a hundred individuals. Several faculty members of IISc have been experts at various Assessment Reports of the IPCC (past and present). Publications from the IISc in the period July 2018 – June 2019 include: South asian monsoon response to remote aerosols⁴¹. Research at IISc Connected with climate change, monsoon etc., is also going on in its Centre for Atmospheric and Oceanic Sciences (CAOS), its Centre for Earth Sciences (CEaS), and the Centre for Sustainable Technologies (CST), in addition to the Divecha Centre (DCCC).

At the CAOS/DCCC, a group studied the long-term trends in the near-surface black carbon aerosols over the Indian region using multilayer primary data from a dense network of observatories⁴². Scientists at the CST are

assessing the impact of climate change across regions and sectors⁴³ and vulnerability and adaptation to climate change, mitigation options in the forest sector.

IISc is also the Indian nodal agency of the bi-national cooperation agency, Indo French Cell for Water Sciences (IFCWS). Its goals involve integrated studies pertaining to water and soils in India, from local (soil-plant profile) to subcontinent scales. The collaboration is in disciplines such as hydrology, geochemistry, remote sensing, agronomy, oceanography, geophysics, soil science and climate science. Collaborations were also initiated with countries in South-East Asia and Africa. Recent PhD students projects listed under IFCWS include: “Analysis of salinity observations in the Bay of Bengal, Impact of Continental Large River Freshwater Flux and Oceanic Precipitation on Sea Surface Salinity along the East Coast of India” (A.V.S. Chaitanya, NIO/LOCEAN) and “Links between tropical Pacific Ocean and Indian Ocean” (M. Shamal, IITM/LOCEAN).

Tata Institute of Social Sciences (TISS) : TISS recognizes the intersection of the natural and the social sciences in the study and research of climate change and sustainability⁴⁴. Its Centre for Climate Change and Sustainability Studies (CCSS) trains young graduates from diverse streams of natural sciences, engineering, architecture, social sciences, and humanities. The Centre has a two year MA/MSc program in the area as well as a MPhil/PhD program. Its faculty members have diverse backgrounds of academic disciplines. They work on climate change mitigation strategies along with goals of environmental protection and human development. Their research on emissions modeling and carbon budgets recognizes the need for addressing the issue of climate change, while at the same time understanding the imperatives of development for countries such as India. A contribution to this debate at the international level was the report on equity and sustainable development⁴⁵. In the area of vulnerability and adaptation studies, the Centre researchers look at impacts and recovery due to climate and weather shocks, e.g. those related to agricultural production⁴⁶, and vulnerability and adaptation linked to regional impacts of climate change. The Centre recognizes the importance of energy access or the use of non-commercial sources of energy in relation to future requirements of developing countries⁴⁷ and studies rural energy supply in the state of Maharashtra. Researchers at TISS have interests also in environmental jurisprudence, regulation and policy, forest rights and governance and environmental movements⁴⁸. CCSS researchers have interests on subjects related to climate, water and

agriculture, with a focus on impact assessment in relation to climate variability and climate change⁴⁹.

CCSS in collaboration with organizations like Delhi Science Forum has organized annual Climate Conferences for the last 10 years which made significant contributions to the evolution of climate policy in India by bringing together scholars and activists in academia, think tanks, non-governmental research organizations and science movements. TISS has recently entered into a partnership with the University of Sydney in Australia for research on climate change and environment. Areas of collaborative research will include the effects of climate change on migration, impacts and responses within human populations, environmental refugees and economic analysis of adaptation to climate change.

Universities

A few universities that collaborate in these areas with research institutes have already been mentioned earlier in earlier sections. In addition, Jadavpur University (School of Oceanographic Studies*, see Ref.^{50,51} and Dept of Economics) and Calcutta University (Departments of Environmental Science, Marine Science and Atmospheric Science) have important research programs in these areas. These efforts are distributed over their separate host departments.

In many universities, the input streams to the postgraduate programs are restricted to the undergraduate qualifications in the host departments with hard disciplinary boundaries between natural and social sciences and humanities and management science. The research and education in this highly interdependent field often do not take place under a united forum that transcends disciplinary boundaries and is fractionated in different educational streams.

Non Governmental Organizations

Centre for Policy Research : The Centre for Policy Research, is a policy think tank in New Delhi which has the Initiative on Climate, Energy and Environment⁵². Its activities and areas of work are in understanding: 1) the global climate change regime; 2) India's energy future - focusing on buildings and electricity sectors; 3) climate and development, and 4) domestic environmental law, governance and regulation, and institutional capacities for strategic environmental governance.

The CPR Initiative's sub-projects include: cities and climate change, air pollution in cities, coordination in accessing climate finance, energy and climate policy including a rural cooking study, state action plans on climate change (SAPCC). Books published by the CPR members include: "India in a Warming World"⁵³ which discusses the shift undergone by India from understanding the climate change problem as a diplomatic challenge to engaging with it as a developmental problem. Another book on international climate change law⁵⁴ assesses instruments and conventions dealing with climate change and explores the linkages between climate change law, migration and trade laws as well as human rights law. Researchers at CPR examined the response of Indian cities⁵⁵ with climate vulnerabilities and risks, and how in future urban India might integrate local development with climate change mitigation and adaptation.

The Energy and Resources Institute (TERI) is a think tank in the field of energy, climate change and sustainability. TERI contributed policy briefs⁵⁶ on building climate resilient infrastructure for the discussions at the G20 summit 2019. TERI School of Advanced Studies has a M.Sc. program on Climate Science and Policy⁵⁷.

Non-Formal Education Sector

Centre for Science and Environment : The Centre for Science and Environment (CSE) is a public interest research and advocacy organization in New Delhi⁵⁸. The associated Anil Agarwal Green College (AAGC) at Alwar is an education and training initiative of CSE serving as a capacity building hub that conducts a number of short and long term courses and training programmes. Examples of their short term courses include: technical workshops on how to build rainwater harvesting systems and decentralized wastewater treatment structures, policy briefings on ecological poverty and food safety. It also has an internship program and a two-month long summer course that attracts students from many countries.

CSE published the Climate Change Reader for Universities⁵⁹, that deals with the science, impacts, politics and sustainable pathways from scientific studies and reports using infographics, case studies and lectures. The book was written keeping the UGC syllabus in mind. CSE's flagship journal, Down to Earth⁶⁰, is a fortnightly magazine which covers climate change and other environmental concerns. The magazine has a children's supplement (see also publications for "young and curious" on climate change^{61,62}).

* This group's focus of work has been in the Sundarban area in West Bengal and in collaboration with many academic and NGO groups (e.g. WWF India) and on the Sundarban estuarine system.

Discussion and Conclusion

Climate change has much wider societal implications than just the science and technology underlying the phenomenon. Economically challenged citizens of countries like India have special vulnerabilities. The first victims of climate change, e.g. tribals in forest habitats and fishing communities are hardly responsible for the cumulative effect of greenhouse gases in the atmosphere. Yet precisely these vulnerable people have little exposure to education and few coping mechanisms.

In India's schools, climate change as a topic appears in class 9 in Social Science (CBSE syllabus). At the high school children encounter material on climate change if they take Geography as an elective subject, and learn about the chemistry of environment if they take Chemistry.

Research and educational efforts in this interdisciplinary field within India remain fragmented and meager compared to the scale of the challenge. Dubash⁷ notes that the quality and intensity of the debate around climate change is hampered by the relatively limited availability of information and analysis, and even the material that does exist is not in wide circulation. He also notes the shortage and the narrow range of participants in India's climate debate.

This raises the question as to the extent scientific community in India has been involved in shaping the international discourse. The IPCC, an important forum in this context, is currently in the process of generating the 6th periodic Assessment Report (AR6) about knowledge and response to climate change. Participation of India based experts in the three Working Groups in AR6 is an overall 4% among the authors. That is, there are 28 Indian experts (of whom 8 are women) out of the total of 721 experts from 90 countries selected by the IPCC[†]. This overall percentage of Indian researchers remains similar to those in the earlier AR5 (2014) and AR4 (2007)⁶³. However participation in AR6 WG-I, which examines the physical science underpinning climate change is lower (6 Indian experts out of 235 or 2.5%). Indian experts are better represented in the Working Groups on vulnerability and adaptation (WG-II) and mitigation (WG-III). Here 12 Indians out of 260 and 10 out of 231 are participating in WG-II and WG-III respectively. WG-III has an Indian Co-Chair, P. R. Shukla. The limited participation of Indian experts in the IPCC process may be emblematic of this overall shortage of knowledge and research base especially

in the sciences. In addition, while research is being conducted in the various institutions, there may be sparse coordination among stakeholders.

Problems of the design of India's National Action Plan on Climate Change (NAPCC), which consists of eight missions, including the National Mission for Strategic Knowledge for Climate Change (NMSKCC) have been analyzed⁶⁴ by S. Byravan (IFMR) and S. Chella Rajan (IIT Madras) [see also the articles by D. Raghunandan and by Anu Jogesh and Mridula Paul in this issue]. The mission design of NMSKCC did not strengthen interdisciplinary research. The nodal agency, Dept. of Science and Technology, supports the natural sciences, but there is a need for interdisciplinary collaborative research that cross-fertilizes with social sciences, economics and other disciplines. Byravan and Chella Rajan⁶⁴ also point to the need for creation of financial instruments to direct funding towards institutions and organizations at the national, state and district levels, enabling local-level institutions to raise research questions and to take part in data generation and monitoring programs.

Information about the impact of climate change is vital to policy formulation. Agriculture being the mainstay of a large part of the populace, there is clearly a need for weather prediction at the block-level⁶⁵. Modeling is essential to study the impact of long-term climate change and for developing adaptation strategies. Good climate modeling and climate change projections require climate data by district, block and panchayat levels. N. H. Ravindranath (IISc) points out⁶⁶ that while available data may be adequate for the government to get a broad picture of how climate change impacts rice production, forests, etc. at the national level, this is not sufficient for the purpose of planning adaptation or development projects for helping communities. Long-term projections have the need to improve models for different crops with soil data, water data, climate data, and crop data of a particular district. Currently there is no plan for such a data collection network across the country. A long-term programme to make climate change projections at the district level can take shape by creating a network of institutions throughout India with a mission-like focus that will deal with agriculture, forests, health, transportation, infrastructure sectors and others.

The research base in the area of the science of climate change in India needs to be broader in scope and have a strong foundation of evidence. For example, there is a new

[†] <https://archive.ipcc.ch/report/authors/report.authors.php?q=35&p=&p>

About 40% of the 28 Indian experts in AR6 are from four Institutions : IISc (3), IITM Pune (2), IIT Bombay(2) and TERI(4)

and rapidly advancing area of science called attribution science for extreme weather events⁷ [see also the article by Nagraj Adve in this issue]. Confidence in the attribution⁶⁷ of extreme heat and cold events due to anthropogenic climate change is highest, followed by hydrological drought and heavy precipitation. There is rather little confidence in the attribution of tropical and extra-tropical cyclones to climate change. Research on attribution science is still in a preliminary stage⁶⁸ in India. This is an area that India can direct more efforts into.

Formal scientific research and policy work do not intersect substantially in India. In spite of much research in the agricultural sector and related institutions there is little downstream translation into action of the new knowledge at farm level on adaptation. This appears to be the case for climate change research as well. This disconnect may actually be fostered by the structural problems in our higher educational system such as too great an emphasis on disciplines and opportunities for work.

In conclusion, climate change and its effects are being studied in several organizations in India. As an academic field, the interdisciplinary reach of climate change goes far beyond the scientific and technological concerns. Unfortunately, the siloed thinking and the rigidity of our formal educational structures often make it difficult for researchers or students at postgraduate or doctoral levels to transcend disciplinary barriers except in a few select institutions. Much of the research in India on climate change is scientific research. There are also organizations involved in policy advocacy or in non-formal education on climate change. Translation of research into action needs more attention. At the national level there is a case for greater coordination between different bodies involved in research, education and policy matters.

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⁷ Extreme events are, for example, extreme cold or heat events, droughts, extreme rainfall, tropical and extra-tropical cyclones, wildfires, etc.

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