Impact of climate change on agriculture ecosystems and resilience for sustainable development under the Global Framework for Climate Services in India

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Agriculture is affected due to the impact of climate change on soil, land, water and the atmosphere. Agriculture is also a significant contributor to greenhouse gas emissions, directly or indirectly. The challenge lies in the reduction of emissions without impacting food production and yield. With the increase in air temperature and extreme events of rainfall as the probable indicators of climate change, there can be impacts on various components of the agroecosystem, which include crop yield, soil quality, pest and disease infestation, crop loss, irrigation water demand, etc. This will, in turn, impact food security. The development of novel adaptation techniques and strategies for agriculture and surveillance of resources is needed to tackle the adverse effects of climate change. This article discusses the impacts of climate change on various components of the agroecosystem and how to achieve resilience for sustainable development. Various national-level programmes for climate change resilience in agriculture have been implemented in India to incorporate climate information into agricultural development by integrating climate services into practices and policies for future food security.

Keywords: Agroecosystems, climate change, food security, remote sensing, sustainable development.

TRANSITION to sustainable agriculture to meet the world's food demand, projected to increase by at least 60% above 2006 levels, under the climate change scenario is a challenge[1]. To keep the increase in global temperature below the crucial ceiling of 2°C, emissions will have to be reduced by 70% by 2050. Climate action failure is one of the top global risks in 2021, both in terms of likelihood and impact (Table 1). The challenge lies in the reduction of emissions without impacting food production and yield. In this article, we discuss the impacts of climate change on various components of the agroecosystem and how to achieve resilience for sustainable development under the World Meteorological Organization (WMO), Global Framework for Climate Services (GFCS) in India. In 2012, WMO established GFCS with the vision to 'enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale'. GFCS provides a clear and structured approach to developing climate services and the science to support them[2].

The ecological consequences of techno-centric approaches to food production, though essential and also appreciated for many decades, are now visible in most parts of the world with a negative environmental impact on agriculture sustainability. Soils have been impacted considerably due to intensive agriculture and water availability. Throughout the world, soil salinity is an issue in 20% of total cultivated and 33% of irrigated agricultural lands[3]. A study has reported that yield reduction due to soil salinity has led to an economic loss of 1.2 billion US dollars in India and 27.3 billion US dollars globally[4]. An increase in coastal flooding and sea-level rise are leading to increased salinization of land and water. With the increase in air temperature and extreme events of rainfall as the probable indicators of climate change, soil salinity may be further impacted[5,6]. In India, 2% of the total geographic area is salt-affected, which threatens the country's sustainable agriculture and food security[6]. Out of the 121 Mha of degraded land, 6.73 Mha is covered by salt-affected soils. It is estimated that climate change poses a major soil salinization risk to coastal Bangladesh, with a rise of 39% in saline areas by 2050 (ref. 7). Corwin[8] has discussed agricultural areas where the

Table 1. Global risks of 2021 (ref. 78)

Top global risks by likelihood	Top global risks by impact
Extreme weather	Infectious diseases
Climate action failure	Climate action failure
Human environmental damage	Weapons of mass destruction
Infectious diseases	Biodiversity loss
Biodiversity loss	Natural resource crises
Digital power concentration	Human environmental damage
Digital inequality	Livelihood crises

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change in weather patterns has increased soil salinity in coastal areas and areas with a shallow water table. He has also discussed the water-scarce areas where salinity has increased due to the use of groundwater as an irrigation source[8]. Climate change could accelerate the pace of soil salinity development, particularly in arid and semi-arid regions, and thus, environment-friendly and socio-economically viable measures need to be adopted to mitigate this damage. Soils also have a major role in regulating carbon dioxide (CO_2) emissions. In arid and semi-arid regions of the world, saline groundwater is a major challenge for managing water requirements for agricultural sustainability[9]. Almost 43% of the world's irrigated area is groundwater-dependent[10], of which India (39 Mha) and China (19 Mha) share the maximum area under groundwater irrigation. Therefore, strategic water management techniques are required to tackle saline groundwater during crop production.

Between 1900 and 2005, globally, the area under irrigation has grown from 0.5 to 3.0 million km^2. Climate change brings in large uncertainties in future demands of irrigation, given the temperature and precipitation variability due to global warming[11–13]. Irrigation uses the largest proportion of water and is responsible for 70% of the global water demand for sustaining 40% of the global food production[14]. In India, irrigation accounts for 80–90% of the total water demand, and the wheat crop is the main driver of the country's irrigation water demand (IWD)[15–17]. Food production/agriculture consumes a large amount of water. Thus, ensuring food security for future generations under resource constraints due to climate change is a big challenge.

To achieve the projected demand according to the rising population, global crop production needs to double by 2050 with a 24% growth rate of crop production per year[18]. Climate change may reduce yields of staple crops by up to 30% due to low productivity and crop failure[19]. Studies have indicated that the yield had reduced with increasing RCPs (representative concentration pathways) for irrigated maize by 10–26% (ref. 20). From 1980 to 2008, there was a 5.5% drop in wheat yield and a 3.8% drop in maize yield globally[21]. Gupta and Mishra[22] showed that the major rice-producing agro-ecological zonings may experience a negative impact of climate change by the end of the 21st century. Averaged across global climate models and scenarios, the CropSyst model-simulated crop yields of the rice–wheat system showed a 7%, 15% and 25% decrease in rice and 10%, 20%, and 34% in wheat for the years 2020, 2050, and 2080 respectively[23]. With global warming, the projected groundnut crop failure increased by a factor of two in South India, while western, central and eastern India are projected to have reduced crop failure[24]. It has also been shown that 15–40% of current rainfed rice-growing areas will be at risk[25]. Eastern and northern India are most at risk, but parts of central and western India may benefit from increased precipitation.

The negative impacts of climate change on soil fertility and mineral nutrition of crops would far exceed the beneficial effects, which would intensify food insecurity, particularly in developing countries[26–28].

In India, in certain states, irrigation has reached a threshold beyond which it may not be able to compensate for the impacts of warming[29] (Table 2). The climate change-induced increased evaporative demand may accelerate the drought condition in the northwestern part of South Asia in the 21st century[30].

Resilience for sustainable development

Agriculture risk assessments hold a key in identifying risk management strategies today and building resilience tomorrow. There is a need to develop a resilience-based holistic system approach to avoid losses and build a risk management capacity at production, market and enabling environment levels for sustaining global agriculture and food systems.

Better-managed irrigation can be an important climate-change adaptation strategy in agriculture that supports improvements in yield and provides other benefits[31]. These measures include farm-level investments in efficient irrigation technologies, deficit irrigation, water harvesting, micro-irrigation, minimum tillage and improved water-delivery systems[32,33]. Rough estimates from global climate models suggest that gross domestic product losses could be as much as a third greater in the absence of autonomous adaptation[34]. Understanding the micro-level adaptive responses of farmers to climate change is important for ensuring that publicly planned adaptation investments have broader impacts[35]. Globally, there is over-abstraction of groundwater, and to reduce its overexploitation, pumping and water-use behaviour in many regions will need to change[36]. Srinivasa Rao *et al.*[37] have identified 30 sustainability indicators for climate-resilient agriculture in India that are particularly suitable for different agroecosystems of the subcontinent.

Table 2. Change in net irrigated area (thousand hectare) of major agricultural states (data source: Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers' Welfare)

State	2007–08	2016–17
Andhra Pradesh (including Telangana)	4,644	4,877
Assam	140	362
Bihar	3,529	3,101
Chhattisgarh	1,334	1,486
Gujarat	4,233	4,233
Haryana	3,025	3,146
Jharkhand	117	283
Karnataka	3,132	3,104
Madhya Pradesh	6,418	9,876
Maharashtra	3,268	3,163
Odisha	2,158	1,122
Punjab	4,112	4,128
Rajasthan	6,444	8,257
Tamil Nadu	2,864	2,385
Uttar Pradesh	13,085	14,337
West Bengal	3,136	3,105
All India	63,189	68,649

In the following sections, we briefly discuss various programmes that have enabled agriculture resilience to the negative impact of climate change.

National-level programmes for climate change resilience in agriculture

An inter-ministerial committee constituted by the Government of India (GoI) in 2016 on doubling farmers' income (DFT) noted impressive agricultural growth since 1947, indicating farmers' resilience to multiple challenges, including climate variability[38]. However, the sustainability of agricultural growth is a major concern. The report examined the poorest 150 districts in the country based on farm income and climate vulnerability and suggested special attention in terms of technology package, infrastructure and policy support for them. Twenty-nine of these districts were found to be highly vulnerable in terms of double stress arising from low farm income and high climate vulnerability (Figure 1). The country's agricultural structure is dominated by small and marginal farmers, accounting for 85% of the total number of landholdings. The adverse impact of climate will be more on smallholding farmers. The Committee recommended that the deployment of appropriate technology will bridge yield gaps, negotiate the negative impacts of climate change and overcome constraints of water, soil and other resource deficiencies[39,40]. GoI has proposed many national-level programmes that enhance resilience to climate change's impact on agriculture. Some of the flagship schemes are briefly described below.

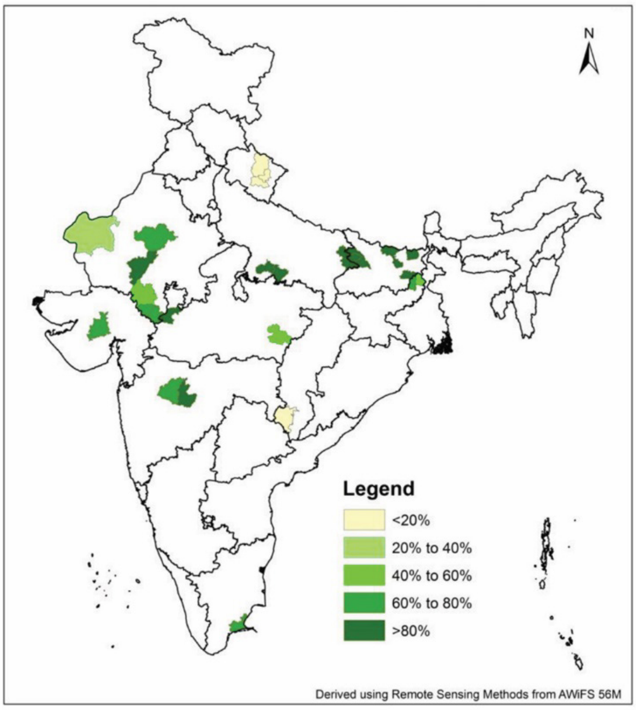

Figure 1. Agriculture area percentage (derived using satellite data) of 29 double-stressed (poverty and climate vulnerability) districts in India, identified in the report of doubling farmers' income.

National Mission for Sustainable Agriculture

The National Mission for Sustainable Agriculture (NMSA) is one of the eight national missions launched by GoI under the National Action Plan on Climate Change (NAPCC) in 2008. The components of NMSA include Rainfed Area Development (RAD), Sub-mission on Agroforestry (SMAF) (to encourage tree plantation on farmland), National Bamboo Mission (NBM), Soil Health Management (SHM), and Climate Change and Sustainable Agriculture: Monitoring, Modelling, and Networking (CCSAMMN). SHM aims to promote integrated nutrient management (INM) through judicious use of chemical fertilizers along with organic manure and biofertilizers for improving soil health and productivity.

Pradhan Mantri Krishi Sinchai Yojana

Pradhan Mantri Krishi Sinchai Yojana (PMKSY), or Prime Minister's Agricultural Irrigation Plan, was launched in 2015 to enhance the coverage of irrigation ('irrigation to every field') and improve water use efficiency in a focused manner with end-to-end solutions like source creation, distribution, management, field applications and extension activities. PMKSY is a combination of three schemes, namely the Accelerated Irrigation Benefit Programme (AIBP), Integrated Watershed Management Programme (IWMP) and On-Farm Water Management (OFWM). AIBP focuses on faster completion of ongoing major and medium irrigation projects. The emphasis of IWMP is on ridge-area treatment, drainage line treatment, soil and moisture conservation, water-harvesting structures, livelihood support activities and other watershed works. OFWM, with the objective of more crop-per-drop, emphasizes on micro-irrigation (MI).

Crop insurance

With the increasing probability of extreme weather in climate change scenarios, crop insurance is essential to protect farmers against various agricultural uncertainties and risks. In 1985, with the Comprehensive Crop Insurance Scheme, GoI started providing widespread crop insurance. This was later replaced by the National Agriculture Insurance Scheme. In 2016, GoI launched an advanced crop insurance scheme known as Pradhan Mantri Fasal Bima Yojana (PMFBY) or Prime Minister's Crop Insurance Plan[41]. This is the third-largest crop insurance scheme in the world in terms of premiums.

PMFBY is an area–yield insurance, where the village panchayat is the minimum insurance unit for major crops and crop yield, derived through crop-cutting experiments, is the index of insurance. PMFBY is a technology-driven scheme. It uses remote-sensing data from satellites and unmanned aerial vehicle for area estimation, yield estimation, loss assessment, risk zoning, etc., to ensure early settlement of claims to eligible farmers against their crop yield loss[42,43].

Gramin Krishi Mausam Sewa: operational agromet advisory services in India

It has been observed that farmers who have access to early-warning systems such as weather forecasting can better cope and adapt to a changing climate. They plan better farming activities, including the choice of crop varieties to plant, on having access to weather forecast information[44].

In 1945, GoI launched weather services to farmers through 'Farmers' Weather Forecast'. The agro-met advisory services (AAS) bulletin in the country was started in 1976, and demand for such services has increased gradually. Further, it was upgraded to a multi-institutional programme with integrated agro-met advisory services in 2006 for district-level agro-advisory services through 130 agro-meteorological field units (AMFUs) covering 683 districts of the country under the Gramin Krishi Mausam Seva (GKMS)[45–47].

Under GKMS, information is provided on weather forecasts and crop-specific advisories on agricultural operations at the district and block levels based on medium and extended-range weather forecasts. This contributes to forecast-based crop/livestock management strategies and operations aimed towards promoting sustainable agriculture and safeguarding the livelihood of the farming community.

Agro-met advisories are being disseminated through farmer awareness programmes (FAP) and other non-governmental organizations and private companies under the public–private partnership (PPP) model. The findings of an impact study conducted by the National Centre for Applied Economic Research (NCAER), New Delhi for estimating the economic benefits of advisory services to farmers during April 2018–March 2019 under GKMS were encouraging, with an estimated annual income gain of Rs 12,500 per agricultural household due to the improvement in weather forecasts[48–50].

Satellite remote sensing for the study of climate change vis-à-vis agro-ecosystems

The Government report on DFI recommended the use of advanced technology for improving the resilience of farmers to the impact of climate change. One such advanced technology is satellite remote sensing.

India has a long tradition of using satellite data for agricultural applications. From monitoring coconut root wilt in Kerala in 1969 to the current operational applications of crop forecasting, drought assessment, crop insurance, etc. the remote sensing applications in agriculture have grown manifold[51,52]. Navalgund and Singh[53] reviewed a large number of climate change studies that were carried out in the country using space-based observations. These included spatial methane inventories from paddy rice[54], livestock[55] and wetlands, and the study of seasonal patterns of CO_2 and carbon monoxide.

Cropping system analysis

Cropping system analysis is useful to explore the sustainability of the agricultural system and helps generate various important parameters that are useful in climate change impact assessment[56]. Multi-temporal remote sensing data help in mapping cropping patterns and crop rotation, and also evaluate the efficiency of the cropping system through several performance indicators. IRS-AWiFS and Radarsat ScanSAR have been used for state and district-level cropping system mapping in five states of the Indo-Gangetic Plains (IGP) of India, i.e. Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. The state-level spatial databases of various agro-ecological parameters such as rainfall, soil texture, physiography and problem soil distribution, along with remote sensing-derived agricultural areas, have been used to assess the area suitable for crop diversification in Punjab, India[57,58].

Precision farming

Precision farming (PF) or site-specific farming caters to the spatial and temporal variability of crop and soil parameters and adjusts management practices accordingly. PF achieves the dual objectives of improving the input use efficiency and reducing environmental degradation[59]. PF practices using high-tech equipment can lower greenhouse gas emissions by selective application of agricultural inputs based on the needs of the fields[60–62]. The use of PF in India is still a challenge, considering the high percentage of small and medium landholdings. Mandal and Maity[63] have discussed the scenario and strategies for the adoption of PF in small farms in India. In recent years, geospatial technologies have enabled making informed management decisions aimed to increase crop production and implement PF[64,65].

Crop intensification

The cropping intensity in India is only 139%, indicating that only 39% of the area is cropped twice a year. To increase agricultural production, especially of oilseeds and pulses, and improve farmers' income, there is a need to increase the cropping intensity. A remote sensing-based estimate shows that the rice-fallow area in India is nearly 12 million ha, i.e. around 30% of the rice-grown area in the country[66]. A study jointly carried out by Mahalanobis National Crop

Forecast Centre (MNCFC), New Delhi and National Remote Sensing Centre (NRSC), Hyderabad under National Food Security Mission (NFSM), for six states in eastern India (Assam, Bihar, Chhattisgarh, Odisha, Jharkhand and West Bengal) showed that there was 8.34 million ha post-*kharif* rice fallow area in these states, of which 3.261 million ha was suitable for growing short-duration *rabi*-season crops (pulses and oilseeds)[67].

In the states of North East India, large areas of jhum land (shifting cultivation areas) constitute a major component of the wasteland. The abandoned jhum lands can be used for growing horticultural crops, which can improve land use and also increase farmers' income. Under the CHAMAN (Coordinated Horticulture Assessment and Management using geoinformatics) Project, 24 districts of 8 NE Indian states were selected for horticultural crop expansion in cultivable wastelands. The abandoned jhum lands were identified using satellite data and assessed for their suitability for growing different horticultural crops based on soil, physiography and weather parameters[68]. This kind of crop intensification planning will not only improve farmers' income but also enhance resilience to climate change impact.

Impact assessment of disasters in agriculture

Various researchers have reported that the frequency of disasters and extreme weather is going to increase with climate change. Agriculture in India is prone to several disasters, such as droughts, floods, cyclones, heavy rainfall, hailstorms, heat waves, and pests and diseases. Among these, drought is a major disaster, considering that only 47.2% of the cropped area of the country is irrigated. Drought assessment using satellite and meteorological data is an operational programme of the Ministry of Agriculture, GoI, under the NADAMS (National Agricultural Drought Assessment and Monitoring System) Project, which was initially developed at NRSC, Hyderabad, Indian Space Research Organisation[69,70].

In addition to the operational drought assessment, remote sensing data have also been used to assess the impact of various disasters, such as cyclones[71], floods[72], hailstorms[73], crop diseases[74,75] and pest infestation[76]. Most of these assessments are qualitative. There is a need to accurately quantify the crop loss due to any disaster. Early warning of disasters is also an essential requirement. Additionally, to improve resilience, it is necessary to map the vulnerability zones of different disasters and promote adaptation measures in highly vulnerable areas.

Conclusion

To ensure food and nutrition security in the face of the growing demand for food and increased competition for natural resources and the climate crisis, there is an urgent need to identify suitable opportunities for environmental, economic and social synergies. The agriculture sector can be considered a driver of economic development based on resilient production with efficient use and management of natural resources. The United Nations Member States adopted seventeen Sustainable Development Goals (SDGs) in 2015 as a universal call of action to end poverty, protect our planet, and ensure that all people enjoy peace and prosperity by 2030. Global efforts are synchronizing in the form of commitments made by the countries in the framework of the 2030 Agenda, the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, and Nationally Determined Contributions to transform agriculture with an integrated and multidisciplinary vision and generate an enabling environment for this purpose.

The agroecosystem is a complex system within which changes are driven by the joint effects of economic, environmental, political and social forces. It is the sector most vulnerable to climate change due to its high dependence on climate and weather. GFSCS of WMO has identified agriculture and food security as one of five main areas at the global, regional, national, state and local levels to address the implications of climate change. It has been well recognized that climate change and increasing climate variability affect food security in all four dimensions – availability, accessibility, utilization and stability[77]. More frequent and intense extreme weather events are already having significant impacts on food production, food-distribution infrastructure, livelihood assets, human health and food emergencies in both rural and urban areas.

To make life sustainable on the Earth, there is a need to adopt alternative energy resources, look for cleaner technologies, build resilience in agroecosystems and increase adaptations among communities to climate change.

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Received 22 May 2023; revised accepted 12 September 2023

doi: 10.18520/cs/v125/i11/1190-1196