Curriculum Vitae

Dr. Surendra Singh

S/o–Mr. Beeri Singh

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Personal Data:

DoB :08-09-1986
Sex :Male
Nationality : Indian
Marital Status :Single

Strengths:

- Self-Motivated
- Positive Attitude
- Cooperative
- Eager to Learn

Languages Known:

- English
- Hindi

Interests:

- Reading books
- Sketching
- Net surfing

Objective:

- To utilize my capabilities in the field of research and teaching in Developmental economics (Micro- finance, climate change, agriculture) by enhancing participatory activities and knowledge in depth.

Job:

- Research Associate at ICAR- National Institute of Agricultural Economics and Policy Research, DPS Marg, PUSA, New Delhi (8th January, 2018 to present).

- Senior Research Fellow at ICAR- Indian Agricultural Statistics Research Institute, Library Avenue, PUSA, New Delhi (8 December, 2017 to 7th January, 2018).

Educational Qualifications:

- Ph.D.in Economics on the topic "An Economic Analysis of Climate Change Effects on Agricultural Productivity: A Case Study on Climate Vulnerability of Farmers in Bundelkhand Region of Uttar Pradesh to Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow, U.P.

- Qualified UGC NET (Dec. 2011)

M.Phil.

Master in Philosophy (2012) in Economics from Bundelkhand University, Jhansi with 77.70% marks

- M.A. (2010), from Dr. BRA University, Agra in Economics with 64.33% marks.

Graduation:

- B.Sc. (2008), from Dr. BRA University, Agra in Zoology, Botany and Chemistry with 50% marks.

Intermediate:

- 12th (2005), from UP Board, with 48.60% marks

High School:

- 10th (2003), from Rajasthan Board, with 50% marks.

Teaching Expertise:

- Taught B.Com. Classes during 2014-15 & 2015-16 academic sessions in the collage affiliated with Lucknow University, Uttar Pradesh.
- Taught B.A. Classes during 2016-17 academic session in the Ma Sharda Mahila Mahavidhalaya College affiliated with Chhatrapati Shahu Ji Maharaj University, Kanpur, Uttar Pradesh.

Research Expertise:

- Estimation of unit level NSSO data.
- Crop Model Forecasting
- Cross Sectional, Time Series and Panel Data estimation.
- Qualitative Data Analysis (logistic Analysis)
- Sustainable Livelihood Security Analysis.
- Climate Change impact Analysis
- Vulnerability Analysis
- Food Security
- Soil Sustainability
- Agrarian Issue including Marginalization, Feminist Issues

Professional Skills:

Publication:

Policy Paper:

- Impact of Climate Change on Indian Agriculture: An Agro- Climatic Zone Level Estimation, Policy Paper No. 44, ***ICAR- National Institute of Agricultural Economics and Policy Research***, PUSA, New Delhi.

Scopus Index Papers:

1. Naveen, P. Singh, Bhawna Anand, Surendra Singh and Arshad Khan (2019), "Mainstreaming Climate Adaptation in Indian Rural Development Agenda: A Micro-Macro Convergence", ***Climate Risk Management***, Vol. 24, No. 2., ISSN No. 22120963

2. Naveen P. Singh, Surendra S., Bhawna A. and S.K. Bal (2019), "Climate Vulnerability Assessment in Semi-arid and Arid region of Rajasthan, India: An Enquiry into the disadvantaged districts", ***Journal of Agrometeorology***, *Vol. 21, No. 2, ISSN No. 09721665*

3. Singh, S. (2020), "Farmers' Perception of Climate Change and Adaptation Decisions: A Micro-level Analysis of Farmers in the Bundelkhand Region, India" ***Ecological Indicators***, *116: 1-15*

4. Singh, S (2020), "Bridging the Gap between Biophysical and Social Vulnerability in Rural India: the Community Livelihood Vulnerability Approach", ***Area and Development Policy***, Vol. 5, No. 2.

5. Singh, S. and Sanatan, N. (2020), "Development of Sustainable Livelihood security index for different agro-climatic zones of Uttar Pradesh", ***Journal of Rural Development***, *Vol. 39, No. 1*, ISSN- 09703357.

6. Naveen, P. Singh and Surendra, S. (2020), "Dynamics of socio-economic factors affecting climate vulnerability and technology adoption: Evidence from Jodhpur District of Rajasthan", ***Indian Journal of Traditional Knowledge***, *Vol. 19, Issue 1. ISSN No.* 09751068.

7. Naveen, P. Singh and Surendra, S. (2020), "Assessing Potential Impact of Climate Change in Gangetic Plain Region in India: A Regional Level Analysis", ***Journal of Agrometeorology***, Vol. 21, Issue 4. *ISSN No.* 09721665.

8. Rehman, H. and Surendra, S. (2020), "De-stunting growth of crop diversification index: A case study from Malda District, India", ***Ecology Environment & Conservation***, Vol. 26 (February supplementary issue), pp. *S185-S190, ISSN No. 0971765X*

9. Singh, S. (2020), "Assessing livelihood vulnerability of farmers' in backward regions in India", ***Indian Journal of Agriculture Research****, Vol. 54, No. 3.*

10. Singh, S. (2020), "Does India Active Agenda 2030 Targets: A Multiple Lens Analysis", ***Data- in-brief*** (accepted).

11. Singh, S. and Alka, S. (2020), "Climate risk management strategies in vulnerable regions of India", ***Indian Journal of Traditional Knowledge***, Vol. 19, No. 2. (Under review).

12. Singh, S. and Alka, S. (2020), "Is Agenda 2030 targets achievable for Developing Countries: A Multiple Lens Analysis", ***Journal of Rural Development*** (under review).

13. Singh, S. (2020), "Assessment of Climate change impact on wheat yield in Western Dry Region: A District level analysis" ***Indian Journal of Ecology***, Vol. 47, Issue, 2.

UGC- listed Papers:

14. Singh, S. and Nayak S. (2018), "Planned Adaptation Strategies and Climate Variability: Evidences from NSSO Households Level Data", ***Research Review International Journal of Multidisciplinary***, Vol. 3, No. 10, *ISSN No.* 24553085

15. Singh, S. and Nayak, S. (2018), "Application of Indicators for Identifying Climate Vulnerable Areas in Sub-tropical regions of India", ***Asian Journal of Multidimensional Research***, Vol. 7, No. 11, *ISSN No.* 22784853.

16. Singh, S. (2019), "Determinants of Agriculture Production in Uttar Pradesh, India: A Regional Analysis", ***Research Review International Journal of Multidisciplinary****, Vol. 4, No. 1, ISSN No.* 24553085

17. Singh, S. (2019), "Soil Health Security in India: Insights from Soil Health Card Data", ***Research Review International Journal of Multidisciplinary****,* Vol. 4, No. 3, *ISSN No.* 24553085

18. Singh, S. and Alka, S. (2019), "Escalating Food Security Status in Gujarat State of India", ***Asian Journal of Multidimensional Research****,* Vol. 8, No. 3, *ISSN No.* 22784853.

19. Singh, S. and Md. Awais (2019), "Climate Variability and Rice Production in North India", ***Economic Affairs****, Vol. 64, No. 2. ISSN No. 0424-2513.*

20. Singh, S. and Md. Awais (2019), "Climate Change and Agricultural Productivity: A Theoretical and Empirical Review", ***Global Journal of Bio-Science and Biotechnology***, Vol. 8, No. 3. *ISSN No.* 22789103.

21. Singh, S. and Alka, S. (2019), "Irrigation Development and Equity Implications in India: Revisiting Sustainable Development Agenda", ***Environment and Ecology***, Vol. 37(4B), *ISSN No.* 09700420.

NAAS- index Papers:

22. Singh, S. and Alka, S. (2019), "Farmers' Perception of Climate Change and Livelihood Vulnerability in Rainfed Regions of India: A Gender-environment Perspective", ***International Journal of Environment and Climate Change***, Vol. 9, Issue, 12, ISSN No. 25818627.

23. Singh, S. (2020). "Mapping Livelihood Vulnerability in Slum Households: A Gender Perspective, ***International Journal of Agricultural Sciences***, Vol. 12, No. 1, *ISSN No.* 09759107.

24. Singh, S. (2019), "Are Large Area Sustainability Champions?. A double delinking analysis of environmental performance of global cities", ***Journal of Global Economy***, Vol. 15, No. 4., ISSN No. 22781277

25. Singh, S. and Alka, S. (2019), "Climate Change and Migration: Adapting to Crisis", ***Asian Journal of Environment & Ecology***, Vol. 11, No. 3., ISSN No. **2456-690X**

Peer- reviewed Papers:

26. Singh. S. (2013) "MGNREGA: 100 days employment guarantee in Bundelkhand region (M.P.)?." ***International Journal of Management and Development Studies***, Vol. 2, Issue 4., *ISSN No.* 23200685

27. Singh, S. and Sanatan N. (2014),"Climate Change and Agriculture Production in India" ***European Academic Research***, Vol.2, No. 6, *ISSN No.* 22864822

28. Singh, S. and Sanatan N. (2017), "Climate Variability and Agricultural Productivity in Uttar Pradesh, India: Evidence from Panel Study", ***Journal of Regional Development and Planning***, Vol. 7, Issue 2. *ISSN No.* 22779094

29. Singh, S. and Alka S. (2018), "Assessment of Climate Induced Vulnerability in the Bundelkhand Region, India: An Application of Indicator Based Approach, ***UPUEA Economic Journal***, Vol. 11, No. 3 *ISSN No.* 09752382

30. Singh, S. and Nayak, S. (2018), "Land Inequality and Agricultural Sustainability in Uttar Pradesh, India: A Regional Analysis", ***Asian Journal of Science and Technology***, Vol. 9, No. 11, 09763376

31. Singh, S. (2018), "Performance of Indian Agriculture: A State Level Analysis", ***Social Science Researcher***, Vol. 4, No. 2, *ISSN No.* 2319-8362.

32. Singh, S. (2020), "Agricultural Development in India: A State-level Analysis", ***South Asian Journal of Social Studies and Economics***, Vol. 6, No. 2, pp. 17-34.

33. Singh, S., Alka, S. and Santan, N. (2020), "Future climate change impacts on crop productivity in Coastal Regions of India: A Panel Estimation", ***Climate Change***, Vol. 21, No. 21, ISSN No 23948566.

34.

Papers in Edited Books:

35. Singh, S. and Sanatan N. (2016), "The Potential effect of Climate Change on Cash Crops Productivity in Uttar Pradesh: Evidence from Panel Study", in "***Issues in Rural Livelihood***" (eds.) Sheeladitya Paul, Subikash Chowdhury, Progressive Publishers, Kolkata, ISBN No. 97881180642364.

36. Sanatan, N. and Surendra S. (2016) "Impact of Climate Change on Agriculture: Approaches, Extent and Dimensions", in ***State and Capitalist Development in India: A Political Economic Perspective*** (eds.) Surinder Kumar and C.S. Verma, Aakar Books Publication, New Delhi, 9789350023730.

37. Singh, S. (2020), "Do Marginal Farmers Vulnerable to Climate Change: A Pragmatic Approach", in ***Social Development of Vulnerable Groups: Issues and Challenges in Contemporary India*** (eds.) Tapas Kumar Dalpati. Ravat Publication, New Delhi.

Papers in Seminar proceedings:

38. Singh, S. and Sanatan N. (2017), "An Assessment of Farm Level Adaptation Strategies in Agriculture: A Case Study of Two Districts of Bundelkhand Region, India", ***Indian Political Economy Association,*** Conference Proceedings, December, 8-9, 2017.

39. Singh, S. and Sanatan N. (2017), "Assessment of Climate Induced Vulnerability in the Bundelkhand Region of Uttar Pradesh: An Application of Indicator Based Approach", ***Indian Journal of Agricultural Economics*** *(summary)*, Vol. 72, No. 3.

Reviewer:

1. Environmental Science and Pollution Research, Springer Nature, Switzerland.
2. Natural Hazards, Springer Nature Switzerland.
3. Ecological Indicators, Elsevier, The Netherlands.
4. Journal of Agribusiness in Developing and Emerging Economics, Emerald insights, U.K.
5. Environment, Development and Sustainability, Springer Nature, Switzerland.
6. International Journal of Disaster Risk Reduction, Elsevier, The Netherlands.
7. Weather and Climate Extremes, Elsevier, The Netherlands.
8. Climate Risk Management, Elsevier, The Netherlands.
9. Indian Journal of Traditional Knowledge, New Delhi.

Paper presented in the Seminars/Conferences:

1. Paper titled "MGNREGA: 100 days employment guarantee in Bundelkhand region (M.P.)?." presented in First Lucknow Social Science Congress, 14-15 March 2013 organized by School for Ambedkar Studies, Babasaheb Bhimrao Ambedkar University, Lucknow.

2. Paper titled "An Economic Analysis of Climate Change and Its Impact on Agriculture Production, presented in National Economics Conference 10-12 May, 2013 organized by Young Economist School at University of Hyderabad, Hyderabad.

3. Participated in the Inter-Conference Symposium of International Association of Agricultural Economists (IAAE), on "re-visiting Agriculture Policies in the light of Globalization Experiences: The Indian Context", organized by Indian Society of Agricultural Economics during 12th -13th October, 2014 at MANAGE, Hyderabad, India.

4. Paper titled "The Potential Effect of Climate Change on Agricultural Productivity in Uttar Pradesh: Evidence from Panel Study, 5th March, 2016 in National Seminar on Current Issues in Rural Livelihood organized by Centre of Social Inclusion, Bankura Christian College, Bankura, West Bengal.

5. Paper titled "The Potential Effect of Climate Change on Crops Productivity in Bundelkhand Region, India: Evidences from Panel Study", 27th to 28th July, 2016 in the 3rd International Research Scholar's Workshop organized by Department of Economics, University of Calcutta.

6. Paper titled "Climate Variability and Agricultural Productivity in Uttar Pradesh, India: Evidences from Panel Study" in the two-day International Seminar on "Poverty, Environment and Sustainable Development Goals in Asia- Pacific" organized by the Centre for Ecological Economics and Natural Resources of the Institute for Social and Economic Change, Bangalore during December 8th- 9th, 2016.

7. Paper titled "Climate Variability and Agricultural Productivity in Uttar Pradesh, India: Evidences from Panel Study" in 53rd Annual Conference of TIES from 22-24 December, 2016 at National Institute of Science Education and Research, Bhubaneswar.

8. Paper titled "Livelihood Vulnerability in the Rainfed regions of India: An Application of Indicators" in 77th Conference of Indian Society of Agricultural Economics, during October 12-14, 2017 at Central Agricultural University, Meghalaya.

Training Course attended:

1. Research Methodology Course in Economics and other Social Sciences for Ph.D. Students 20-30 November, 2012 organized by Department of Economics, University of Lucknow.

2. Research Methodology Course Organised by Council for Social development, Hyderabad, 21-31 January, 2013.

3. Two Weeks Workshop cum Training Programme on Application of Advance Econometric Techniques, 17-28 February, 2014 organized by Department of Economics, Babasaheb Bhimrao Ambedkar university, Lucknow.

4. Workshop on Research Methodology for Ph.D. Students in Social Sciences organized by Institute of Economics and Finance. Bundelkhand University, Jhansi during March 8-17, 2016.

5. Training Programme on Methods and Approaches for Research in Migration Issues organized by Loyola Institute of Social Science Training and Research, Loyola College Chennai, 28 March -1 April, 2016.

6. Orientation Programme on Rural Livelihood and Well Being organized by Institute of Economic Growth, 3-7 may, 2016.

7. Workshop on Econometric Modeling: Techniques and Research Applications" organized by Department of Economics, Shri Mata Vaishno Devi University, Katra, Jammu & Kashmir during 22^{rd} to 26^{th} August, 2016.

8. Three days short-term course on "Panel data Analysis using STATA" during 23^{rd} – 25^{th} November, 2016, organized by Department of Humanities and Social Sciences, National Institute of Technology, Rourkela, Orissa.

9. Course on Quantitative Methods in Labour Research held during February 13-24, 2017 organised by V.V. Giri Labour Institute, NOIDA, India.

10. Course on Methods in Historical Research on Labour held during September 11-15, 2017 organised by the V.V. Giri Labour Institute, NOIDA, India.

Lecture Delivered:

1. Delivered a lecture on Livelihood Vulnerability in Rainfed Agriculture: A Study of Ten Villages of Buldelkhand Region of Uttar Pradesh, India in Research Methodology Workshop & Seminar for Sc/ST Research Scholars entitled "Livelihood, Health and Well-Being of Marginalized Group in India, March 26-30, 2018 at Institute of Economic Growth, New Delhi.

2. Delivered a lecture on NSSO data estimation in "Statistical Data Processing and Use of Unit Level Data of NSSO for Ph.D. Scholars" organizing by Department of Economics, BBA University, Lucknow, Uttar Pradesh, April 23 to May 2, 2018.

Technical Skills:

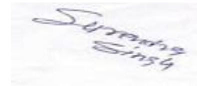
Computer Courses:

- Diploma in Computer Application
- M. S. Office, M.S. Excel, Internet Browsing, R, STATA, S.P.S.S. & E-views (Statistical Packages).
- QGIS

Extra Activities:

- Participated in various co-curricular activities at all level of studies.

Declaration: I hereby declare that the above information is correct to the best of my knowledge.



Date: 28/06/2020

Place: New Delhi **Signature**

1. Sanatan Nayak (Professor)
Department of Economics, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh- 226025. Email Id: sanatan5@gmail.com. Contact No. +919956042761.

2. Tapas Kumar Sarangi (Assistant Director)
National Institute of Labour Economics Research and Development (An Autonomous Insititute under NITI Aayog, Government of India), New Delhi. Email Id: sarangi.tapas@gmail.com. Contact No. +91-011-27787215-17.

Research and Teaching Plan

I have an excellent command of English and Hindi. During Ph.D. work, he got an opportunity to teach Masters Students of Environmental Economics at the Department of Economics at BBA University, Lucknow, thereby equipping himself as a profound and most sought after teacher in the department. I believed in learners centric approach and has always kept students learning's and pursuits in mind while teaching.

I have plans for the future development of the Institute to develop a holistic system, where students excel in becoming the best economics professional in academia, private and government sector. Further, students wishing to chart their career in research will be equipped with advanced and cutting edge tools and techniques in research methodology in the master/ doctoral program so that they can unravel the intricate social and economic problem with much ease, suiting to the stakeholder's needs.

I am working for the last eight years on the issues related to environmental economics, viz., climate change impact on livelihood security, food security and natural disasters. I have in-depth knowledge of natural resource conservation, environmental social cost, common-pool resources, green technology, minimum safe standard and green economy. I was invited as a resource person in the ICSSR funded training program on Research Methodology for Ph.D. students by the Institute of Economic Growth, New Delhi and Department of Economics, BBA University, Lucknow, Uttar Pradesh. He has to his credit delivery of lectures on NSSO unit level data and topics related to environmental economics on several occasions in different forums.

Currently, I am working in the Mega Project ***"National Innovations in Climate Resilient Agriculture".***

I have an ability to handle any task independently and strong capability to accomplish his mission in line with organizational goals.

I have published more than 30 research papers in the reputed- peer-reviewed journals apart from contributing two chapters in the edited books. I have calculated the potential impact of climate change on Indian agriculture using a fixed-effect feasible generalized least square model by using datasets of 320 districts of 16 states during 1966-2011. Estimating climate vulnerability and livelihood vulnerability for Bundelkhand Region was another hallmark of his research. I also ventured on to estimate food security and livelihood security within and between major agro-climatic zones speak of his solid research acumen. He is equipped with advanced statistical knowledge to handle large-scale datasets, viz., census, NSSO, NFHS, time-series, and panel- data.

Dr. Surendra Singh

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Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India

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Adaptation strategies
Barriers
Resilience
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Human- environment approach

ABSTRACT

This paper aims at identifying the key determinants, which influence and motivate farmers to adopt a rational, cost-effective, climate-smart adaptation strategy. Macro data encompasses review of studies using "Scopus database" and Micro data from field survey in dry region of Bundelkhand (Uttar Pradesh), India. Multi-stage sampling technique was adopted to select study sites and respondents. A total of 200 sample households of various land size categories were contacted for collecting data using a well-structured and pre-tested schedule. Study findings revealed that variability in temperature and rainfall has affected adversely to the livelihoods of farmers. Low level of livelihood status, fewer non-farm employment opportunities and low cropped area under irrigation were the main barriers to climate change adaptation. Insurance and credit were the main positive determinants that motivated farmers to adjust farm practices. Early maturing seed varieties and less water consuming crop varieties were the most profitable adaptation strategies. Policy intervention should prioritize eliminating asymmetry in information and communication. Enhancing institutional capacities to forecast weather in small geographic regions accurately and warranting accountability of meteorological department is imperative.

1. Introduction

Anthropogenic induced climate change is being realized all over the world and has resulted in increased global surface temperature by 0.85 °C over the past 100 years. It is predicted to increase further by at least 1.5 °C by the end of the 21st century (IPCC, 2014). Poverty and disadvantage have increased with recent warming and are expected to increase for many populations as average global temperature increase from 1 °C to 1.5 °C and higher (IPCC, 2018). Future risks at 1.5 °C of global warming will depend on mitigation pathway and on the possible occurrence of a transient overshoot. Larger risks are expected for many regions and systems for global warming at 1.5 °C, as compared to today, with adaption required now and up to 1.5 °C. To address of climate change in effective way, the Intergovernmental Panel on Climate Change (IPCC, 2001) has recommended for integrating the potential impacts of climate change into national and local-level development planning by doing proper vulnerability assessment (IPCC, 2001). The vulnerability assessment is typically done by the IPCC's (2001) definition, which encompasses concepts, exposure, sensitivity and adaptive capacity (Vincent, 2004). Researches into vulnerability concepts and metrics are methodologically diverse and complex (Eakin and Luers, 2006). There are three main approaches to measure the vulnerability viz., socioeconomic, biophysical, and integrated (Deressa et al., 2008). The socioeconomic approach involves analysis of social, political and economic aspects of the society (Adger, 1999) while biophysical approach includes mainly the impacts of climate change on attributes like yield, income or both (Fussel and Richard, 2006). The integrated approach which combines both socioeconomic and biophysical aspects has become more common (Nelson et al., 2010; O'Brien et al., 2004).

The available studies indicate that vulnerability, in general, is an individual or group's reduced capacity to cope with, resist and recover from the impacts of a natural and human-made hazard (Birkmann, 2007; Funk et al., 2020). Thompson and Scoones (2009) argued that the biophysical, economic and social contexts of agricultural production are increasingly unpredictable as well as volatile. It is so because such production is becoming more driven by complex and interrelated contextual changes, including increase in natural-resource scarcity, climate change, food demand and administrative regulations. Precisely, the vulnerability of any system (at any scale) is a function of that system's exposure and sensitivity to a range of hazards, as well as its capacity to cope with, adapt to or recover from the effects of such conditions (Smit and Wandel, 2006).

The vulnerability is multidimensional and addresses the micro-level issues of climate change while resilience deals with macro-level issues related to climate change. Srinivasa Rao et al. (2016) suggested that resilience is the ability of system to bounce back and essentially involves judicious and improved management of natural resources, land, water, soil and genetic resources through adoption of best practices. The concept of resilience is central to an understanding of the vulnerability of agricultural sector to climate change. Agriculture depends on

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the resilience of both social and ecological systems. In social systems, resilience pertains to households, communities, and regions, the degree of which depends both on the assets and knowledge the farmers can mobilize and services provided by government and institutions. Climate resilient agriculture (CRA) encompasses the incorporation of adaptation and resilient practices in agriculture which increases the capacity of the system to various climate-related disturbances by resisting damage and ensuring quick recovery.

Climate resilience has broader concept and has macro-level implications, therefore, more emphasis is placed on measures of adaptive capacity in comparing vulnerability among households or between communities within a village (Antwi-Agyei et al., 2014a, b). The resilience framework broadens the description of resilience beyond its meaning as a buffer for conserving what you have and recovering to what you were (Folke et al., 2010). For example, declining agricultural productivity in several Latin American countries due to land degradation reached an unsustainable level in the 1970s. This breakdown prompted some farmers to start experimenting with unconventional methods for land management, in particular low-till alternative to plowing that enhanced soil organic matter and fertility (Derpsch and Friedrich, 2009). The experimental learning approach at small scales, with processes for emergence and cross-scale learning, cause a transformation of the whole farming system.

Adaptation to climate change has drawn attention at global level with the rise in climatic events along with increasing confidence in climate change projection (IPCC, 2014). Adaptation adjusts agricultural activity and management practices towards the existing or predicted climate conditions to reduce the vulnerability and ensures climate-resilient farming systems (Shameem et al., 2014). Adaptive capacity is an important attribute as it describes system's capacity to mobilize resources to respond, recover from, and maintenance functions in response to stresses and shocks. It signifies positive characteristics of the system, which can decrease biophysical and or socioeconomic vulnerability associated with climate change (Engle, 2011).

The ability of agriculture to adapt and cope up with climate change depends on factors such as water resources (Shukla et al., 2019), farm technology (Meena et al., 2019), access to inputs (Jha and Amarnath, 2011), crop varieties adapted to local conditions (Bhatta and Aggarwal, 2015), access to knowledge, infrastructure, agricultural extension services, rural financial markets, economic status and wealth (Panda, 2016), etc. The special report of IPCC (2018) on global warming projected that the impact of large-scale carbon dioxide removal (CDR) deployment could be greatly reduced if a wider portfolio of CDR options were deployed, if a holistic policy for sustainable land management were adopted, and if increased mitigation efforts were employed to strongly limit the demand for land, energy and material resources, including through lifestyle and dietary change. In particular, restoration could be associated with significant co-benefits if implemented in a manner than help restore natural ecosystems.

The adaptation highlights the importance of human beings (farmers) in the execution of rational, effective, and cost-efficient strategies to respond to uncertain climatic conditions. The human dimension of agricultural adaptation identifies farmer's agency as planners, performers, and cultivators working under specific socioeconomic, cultural, and ecological setting (Crane, 2010). The adaptation process at the micro-level encompasses the interdependence of agents through their relationships with each other, with the institutions in which they reside and the resource base on which they depend (Adger, 2003).

The present study is attempts to understand the farmers' perception of climate change and adaptation decision through two ways. Firstly, through a comprehensive review of studies and secondly through household level survey.

1.1. Review of literature: scopus database

In order to understand farmers' perception of climate change, barriers of effective climate change adaptation, climate-resilient adaptation strategies, employment opportunities in less climate-sensitive sectors, the present study has collected studies published in the 'Scopus database' (scopus.com). The Scopus database brings together superior data quality and coverage, sophisticated analytics at one place and combats predatory publishing. Scopus indexes content from 24,600 active titles and 5,000 publishers, which is rigorously vetted and selected by an independent review board, and uses a rich underlying metadata architecture to connect people, published ideas and institutions. Using sophisticated tools and analytics, Scopus generates precise citation results, detailed researcher profiles, and insights that drive better decisions, actions and outcomes.

The literature downloaded around the main subject of climate change using keywords, like 'farmer perception, climate change, agriculture, barriers, indicators, multi-criteria analysis and adaptation for the period 2007–2019. The criteria for review of literature: (i) codifying questions for research; (ii) evaluation of selected studies; (iii) systematic analysis of selected papers; and, (iv) generalization of the results. Framework of literature review, i.e., selection criteria of papers, filtration of papers to avoid duplication and finalising the papers for analysis is presented in Fig. 1.

In first step, author's focus was to identify the problems, barriers and challenges for the effective implementation of climate change adaptation strategy within an agro climatic-zone and between agro-climatic zones. In second step, author used the keywords to restrict the study period. In third step, for all titles that related broadly to the topic of climate change adaptation, author reviewed the abstracts and read the complete articles of all relevant texts as well as for those for which no abstract was available. In last step, papers were analyzed and only those containing explicit references to the climate change adaptation were used.

The study finds differential literature covering the issues of data constrains, application of methodology and findings. After reviewing relevant studies published in the reputed and peer-reviewed journals, the following conclusions emerged. First, farmers are well aware of the adverse effects of climate change on crops and their livelihood. Second, there are many socioeconomic, biophysical, and institutional barriers which restrict the farmer from rational adaptation strategy. Lastly, farmers utilized their past and present experiences to frame climate-smart adaptation strategies.

1.2. Barriers to effective climate change adaptation

Despite the significance attached to climate change adaptation all around the world, there is lack of understanding about barriers which affect execution of adaptation strategies by households everywhere (Antwi-Agyei et al., 2014b). The better knowledge of vulnerability of agriculture-dependent households to climate change requires exploration of barriers that constrain the implementation of adaptation strategies. It is pertinent to assess farmers' acumen on barriers to adaptation strategies and identify the factors affecting their adaptation decisions (Table 1). These factors include accessibility and usefulness of climate information, socioeconomic conditions of farm households, and the supportive institutional mechanisms (Bryan et al., 2009). For example, lack of adaptation options, information on long-run and short-run variations in climate can affect the households. However, small landholding farmers are more vulnerable to high-cost debts and therefore, despite having knowledge about the need to adapt, they fail in it (Kandlikar and Risbey, 2000). Moreover, adaptation to climate change is a costly affair and requires resources in form of intensive labour use (Mendelsohn, 2000). Therefore, farm households facing acute shortage of family labour and income to hire labour may not opt for adaptation. Lack of credit, un-affordability to quality seeds, information gap/unawareness, low credit and labour availability, small landholding size, and poor irrigation facilities limit the farmers to undertake adaptation activities.

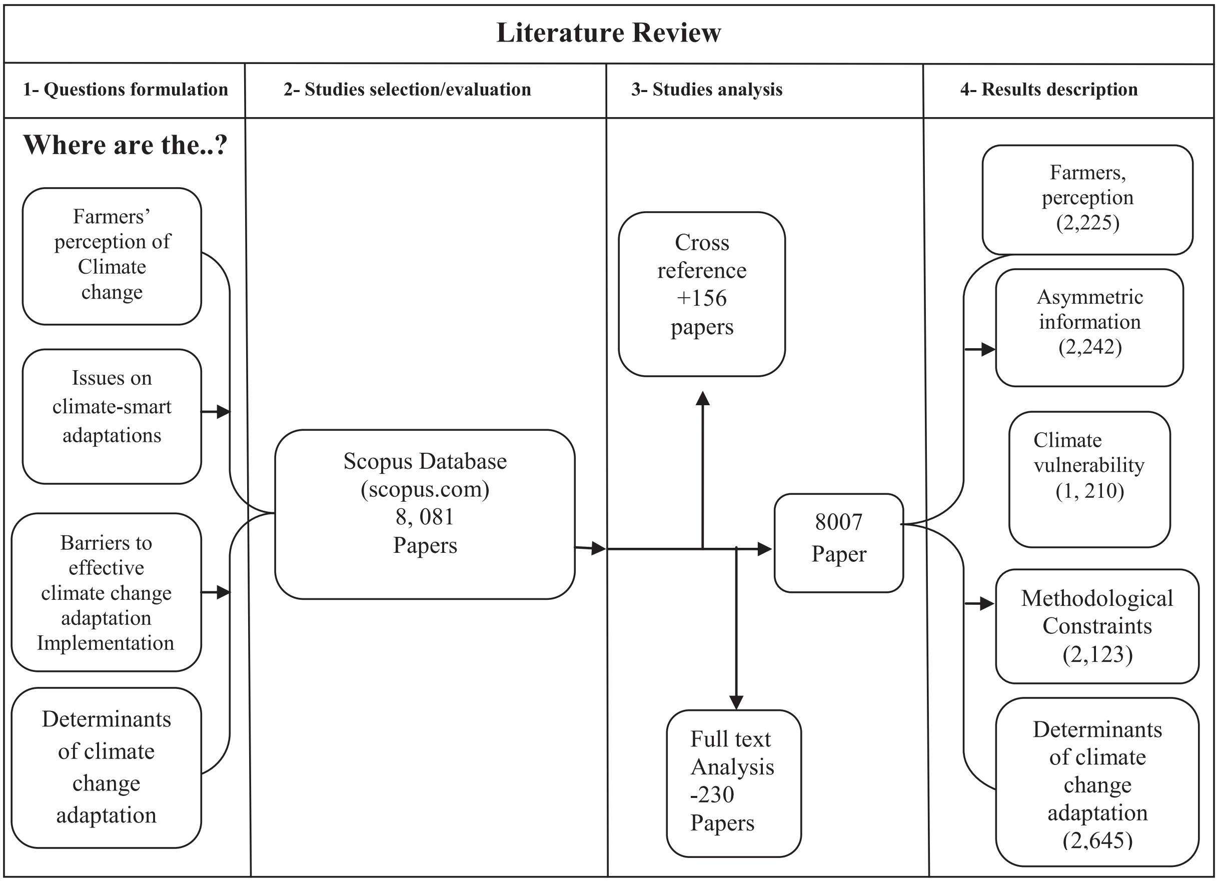

Fig. 1. Bibliographic portfolio of literature review selection.

1.3. *Identification of climate change adaptation in agriculture*

In fact, it is difficult to distinguish between good agricultural practices and 'pure' climate change adaptation options. Climate-smart agricultural practices often derive from efforts and experiences that farmers acquire over time in adapting to various climatic conditions. The justification of calling any adaptation option rather than just good 'old' agricultural practices lies in the process of identifying a certain measure by taking climate change into account. First of all, climate risks have to be analyzed, and then possible solutions are collected and selected based on certain criterion. Finally, the identified solutions are integrated into planned adaptation policies.

The overall objective of adaptation measures is to safeguard farm production from climate change by modifying production systems. The available options to manage climatic risk include like crop insurance, providing financial services and creating opportunities for income diversification (Table 2). Supporting access of markets and market information, combined with infrastructure development can be helpful in exploiting market opportunities. There are several other options of adaptation to climate change that can safeguard agricultural production. For instance, increase in existing production systems by following different practices (changing sowing patterns) and new technologies (irrigation systems, adapted varieties) can help reducing effect of climate change. Following production systems suitable as per changing climatic and environmental conditions (i.e., cropping pattern change) can also minimise the effect of climatic events on agriculture to a great extent. Promotion of agro-biodiversity (i.e., the genetic resources for food and agriculture) supports the natural ecosystem's capacity to mitigate the impact of extreme events (e.g., inclusion of woodlots, protection of water resources, or wetlands).

1.4. *Climate change adaptation: human-environmental approach*

In order to better understand the human-environment relationship in agriculture, academia has developed four methods, i.e., farmers' perception, livelihood vulnerability, resilience, and climate adaptation (indigenous & planned) to manage effect of climate change. Each method has been developed systematically considering the drawbacks of the previous one. The farmers' perception method highlights the forecasting power of a farm household that he/she has developed over time through experience. Farmers use their indigenous knowledge to perceive the changing behaviour of climate and make possible changes in their livelihoods in general and farming practices in particular. The livelihood vulnerability method shows a broader picture of adverse impacts of climate change. This method includes two major components, i.e., biophysical and socioeconomic vulnerability. Biophysical vulnerability determines changes in climate; while poverty, unemployment, social discrimination, and inequalities are key components of socioeconomic vulnerability. The resilience approach describes a much broader picture of system's property that may have to do with the interplay of human and natural systems. Finally, adaptive capacity method is a narrow approach (adopted in present study). It focuses on the specific skills and mechanisms such as knowledge, practices, and land uses that are deployed by human systems to contribute to resilience.

1.5. *Approaches to effective climate change adaptation*

United Nations Framework Conference on Climate Change, UNFCCC (2002), along with Global Science Foundation (GSF) and Niang-Diop and Bosch (2011) have suggested three approaches to the economic assessment of climate change adaptation, viz., cost-benefit analysis,

Table 1
Barriers to climate change adaptation.

Components	Barriers	Source
Technological	1. Limited availability of drought-tolerant crop varieties and location-specific technologies	Suddhiyam et al., 2013
	2. Limited research on climate change and adaptation in agriculture and its various socio-economic dimensions	Menike and KeeragalaArachchi, 2016
	3. Inadequate funds for agriculture R&D activities	
	4. Under-development of irrigation and water-efficient infrastructure in rainfed areas	Rama Rao et al., 2018
	5. High initial cost of investment in water-saving technologies like micro-irrigation, farm ponds, etc.	Rao et al., 2017
Economic	1. Higher cost of adaptation	Spires et al., 2014
	2. Small and fragmented landholding	Ojha et al., 2014
	3. Affordability and timely availability of farm inputs (seeds, fertilizers)	Bhogal, 2016
	4. Inadequate provision of formal financial facilities (for both credit and insurance) to the rural poor and small and marginal farmers	Bhave et al., 2016
	5. Lack of market access to farmers and efficiencies in handling of agricultural produce	Elum et al., 2017
	6. Lack of post-harvest and storage facilities	Bhogal, 2016
	7. Power shortage	Ojha et al., 2014
Institutional	1. Poor coordination and incapability	Mukheibir, 2013
	2. Inequitable distribution of responsibility for adaptation	Baker et al., 2012
	3. Insufficient responsiveness of institutions to change	Bastakoti et al., 2017
	4. Reactionary initiatives	Islam and Nursey-Bray, 2017
	5. Improper leadership	Burch, 2010
Informational/uncertainty	1. Lack of information on credit/insurance facilities and various financial reliefs to the rural farm households.	Rama Rao et al., 2018
	2. Insufficient farm household/State level database to analyze/understand climate impact, vulnerability, and coping capacity.	Patra, 2014
	3. Poor reliability of grass-root level information and lack of computational capacity.	Meybeck et al., 2012
	4. Lack of information on climate changes, adaptation techniques, and weather forecasts at the farm level.	Taraz, 2017
	5. Poor dissemination/extension of technology.	Satishkumar et al., 2013
	6. Unawareness of government welfare and relief programs.	Singh et al., 2012, 2018a, b, 2019
Social/cognitive	1. Underdeveloped human capital (education) which restricts farmers' ability to adopt appropriate measures and adaptation strategies.	Wright et al., 2014
	2. Societal norms and obligations are preventing the adoption of new techniques, the superiority of traditional practices, low self-efficacy, and perception of inability to effectuate change, political and social marginalization, and discrimination.	Le Dang et al., 2014

Source: Retrieved from Singh et al., 2019 and updated.

cost-effectiveness analysis, and multi-criteria analysis.

Approach of cost-benefit analysis (CBA) compares cost and benefits of an intervention over a while (GSF, 2011). The CBA can help decision-makers to adopt the most suitable adaptation, if there is more than one option. Hence, CBA provides a powerful instrument for the economic estimation of climate adaptation options. It needs to follow all the preventive measures in the assessment. Under the cost-effectiveness analysis (CEA), it emphasizes how a well-defined objective achieved in most cost-efficient way. It is slightly different from CBA. The CEA is only used, if it is not possible to assign monetary value to the benefits of adaptation options. The CEA method is an improvised version of CBA, but it cannot estimate multiple costs and benefits occurring in the same unit.

The multi-criteria analysis (MCA) is applied to cases, where a single-criterion approach (such as cost-benefit analysis) falls short (UNFCCC, 2011). The MCA is considered as the most appropriate method to

Table 2
Adaptation strategies in agriculture to climate change.

Adaptation Strategies	Sources (2007–2019)
Cropping pattern change	Deressa et al., 2011; Tripathi and Mishra, 2017
Switch to non-farm activities	Parmeshwar et al., 2014; Nambi et al., 2015; Dhanya and Ramachandran, 2016
Early maturing varieties	Prasad et al., 2014; Kibue et al., 2016
Less water-consuming crop varieties	Loria and Bhardwaj, 2016; Raghavendra and Suresh, 2018
Institutional credit	Jha et al., 2017; Rao et al., 2017; Aryal et al., 2018
Crop weather insurance	Aggarwal, 2008; Nambi et al., 2015;Raghavendra and Suresh, 2018
Crop- water demand management and assured irrigation, watershed management	Bhandari et al., 2007;Soora et al., 2013; Hayashi et al., 2013; Pathak et al., 2014; Jain et al., 2015; Nambi et al., 2015; Loria and Bhardwaj, 2016; Azhoni et al., 2017a, b; Singh et al., 2018a, b; Raghavendra and Suresh, 2018
Application of modern technology	Venkateswarlu and Shanker, 2009
Socioeconomic and institutional interventions	Venkateswarlu and Shanker, 2009; Mwinjaka et al., 2010; Wright et al., 2014; Nambi et al., 2015; Azhoni et al., 2017a, b; Kattumuri et al., 2017; Jha et al., 2017; Rao et al., 2017; Aryal et al., 2018
Out-migration	Murali and Afifi, 2014; Chandan et al., 2018
Delaying sowing date	Prasad et al., 2014; Jain et al., 2015; Loria and Bhardwaj, 2016; Pradhan et al., 2018;
Switch to drought and flood-tolerant varieties	Jain et al., 2015; Nambi et al., 2015; Fischer et al., 2016; Loria and Bhardwaj, 2016;Raghavendra and Suresh, 2018
Intercropping, mixed cropping	Kattumuri et al., 2017; Raghavendra and Suresh, 2018; Pradhan et al., 2018
Judicious use of bio-fertilizers	Nambi et al., 2015
Integrated crop-livestock management	Prasad et al., 2014; Kattumuri et al., 2017
Agroforestry	Prasad et al., 2014
Planted trees surrounding fields	Kaur et al., 2013; Prasad et al., 2014

Source: Various studies (2007–2019).

accomplish decision making in the field of adaptation to climate change. The strength of MCA is that it allows both quantitative and qualitative data, and can thus compare monetary and non-monetary units directly (Brooks et al., 2009). It also allows a much broader set of criteria than other approaches, as well as elements that may be difficult to quantify (Haque et al., 2012). It thus allows the application of factors in non-market sectors and can be broadened out to consider wider attributes, i.e., acceptability and equity of the adaptation options (Bruin et al., 2009).

In view of the above, this paper aims at identifying the key determinants which influence and motivate farmers to adopt a rational, cost-effective and climate-smart adaptation strategy. The paper has addressed following key questions: what are the key barriers to effective climate change adaptations? What are the major climate adaptation strategies followed in Indian agriculture? How a farmer decides to choose a rational and cost-effective adaptation strategy among the available strategies? What are the socioeconomic and biophysical determinants influence and motivate farmers to adopt a rational and cost-effective adaptation strategy? Is climate change adaptation a win-win option?

The paper is organized into five sections. Section 1 describes the importance of problem; Section 2 provides methods and materials encompassing data and analytical tools used; Section 3 presents results of study while Section 4 summarizes the discussion and the last Section presents the conclusion and policy implications.

2. Methods and materials

2.1. Study area

The present study is undertaken in Bundelkhand region of Uttar Pradesh in India. Uttar Pradesh is the most populous state and plays a vital role in India's food and nutritional security by contributing to about 18% of the country's total food grain production in 2016–17 (GoI, 2018). Geographically, Uttar Pradesh is divided into four economic regions, viz., Western, Central, Eastern, and Bundelkhand. This study was undertaken in two districts of Bundelkhand region, viz. Jalaun and Jhansi, owing to the preponderance of droughts in the region (Fig. 2). Compared to any other region of Uttar Pradesh, Bundelkhand is historically more vulnerable to climate change. The region had experienced drought once in every 16 years during the 18th and 19th century, whereas it increased to thrice during 1968 to 1992, and now it become the recurrent annual phenomenon (GoI, 2017). The average annual rainfall of the region continued to be below average during 2004–2017. The severity of low rainfall was such that 40% of the net sown area remained fallow, which resulted in 30% less food grain production (NRAA, 2018).

2.2. Socio-economic features of Bundelkhand

The status of socioeconomic features of Bundelkhand region vis-à-vis Uttar Pradesh and all-India are described in Table 3. The socioeconomic variables reflect that dependency rate is higher, whereas workforce participation, literacy rate and per capita income of the region are relatively low compared to Uttar Pradesh and India. Further, all the demographic characteristics such as Sex Ratio, Crude Birth Rate, Crude Death Rate of the region are significantly inferior to those of Uttar Pradesh and India. The head count ratio of poor people living in this region is also much higher compared to all India level. The region is also lagging behind in access to basic amenities, like cooking, drinking water, medical facilities, all seasonal houses, and toilet facility compared to those of Uttar Pradesh as well as India.

2.3. Sampling framework

A field survey was conducted to elicit information on farmers' perception of climate change, agricultural extension services, and selection of adaptation strategies used by farm households to cope with climate change. A multi-stage sampling technique was opted for the sample selection. In first stage, from a total of 13 districts in Bundelkhand region, 2 districts (one developed district, i.e., Jhansi and one developing district, i.e., Jalaun) were selected based on different hydrological, climatic, soils and agricultural parameters. There are five sub-divisions (i.e., *Tehsils*) in each selected district, and at second stage, all five *Tehsils* from each district were chosen. In third stage, one Development Block from each *Tehsil* was chosen purposively. In fourth stage, one village from each selected block was chosen randomly. Finally, 20 farm-households from each village were selected randomly. Thus, a total of 2 Districts, 10 *Tehsils*, 10 Development Blocks, 10 Villages, and 200 farm-households were selected for the study. This study has adopted three criteria in selection of farm-households. First, villages selected in a way that were closer to the district headquarter. Secondly, the sample households had easier access to inputs, institutional facilities, and management. Lastly, the study includes all land size groups, such as marginal (< 1.0 ha, ha), small (1–2 ha), semi-medium (2–4 ha), medium (4–10 ha), and large (> 10 ha) categories of farms. The preliminary information on the farm-households was collected from the office of Head of village.

A well-designed survey schedule was used to record farmers' perceptions, understanding of climate change, experiences on climate variability, and extreme events over the past decade. Likewise their choice of adaptation and possible reason for observed changes, if any. During the survey, information were specifically asked to farmers about their experience of changing temperature and rainfall pattern over the past decade. Also, the schedule tried to investigate adjustment in farming practices in response to climate change.

2.4. Selection criteria of adaptation option in agriculture

The present study has adopted novel criteria for the adoption of climate change adaptation. This was taken into consideration from the fact that the process of choosing the right method of adaptation happen in the uncertain environment of climate projections and continuous change. There is often no definite answer to question like:

- How is the local climate likely to change, and how fast?
- How sensitively will certain agricultural systems respond to this change?
- Will potential adaptation options perform well, and will they pay off financially in the long run?

For subsistence farmers in rural areas, who generally have low adaptive capacity, many of the choices will require putting in an enormous effort. Hence 'choosing wrong can be costly, even deadly' (Leary et al., 2007). According to Leary et al. (2007), criteria for the selection of adaptation measures might be:

- Economic and social benefits;
- Consistency with development objectives;
- Environmental impacts and spill-over effects;
- Cultural acceptance and social feasibility.

2.5. Estimation method

The present study has adopted multi-criteria analysis (binary logistic model) because its underlying assumptions are less restrictive than those of other models and it is free from problems with the use of ordinary least square (Gajurati, 2004). The adaptation strategy is the dichotomous dependent variable (Y) of this model having a binary value of one (1) if the farmer adapts to climate change using various strategies, and zero (0) if otherwise. The model also assumes that the use of adaptation strategies is a log-linear function of the exogenous

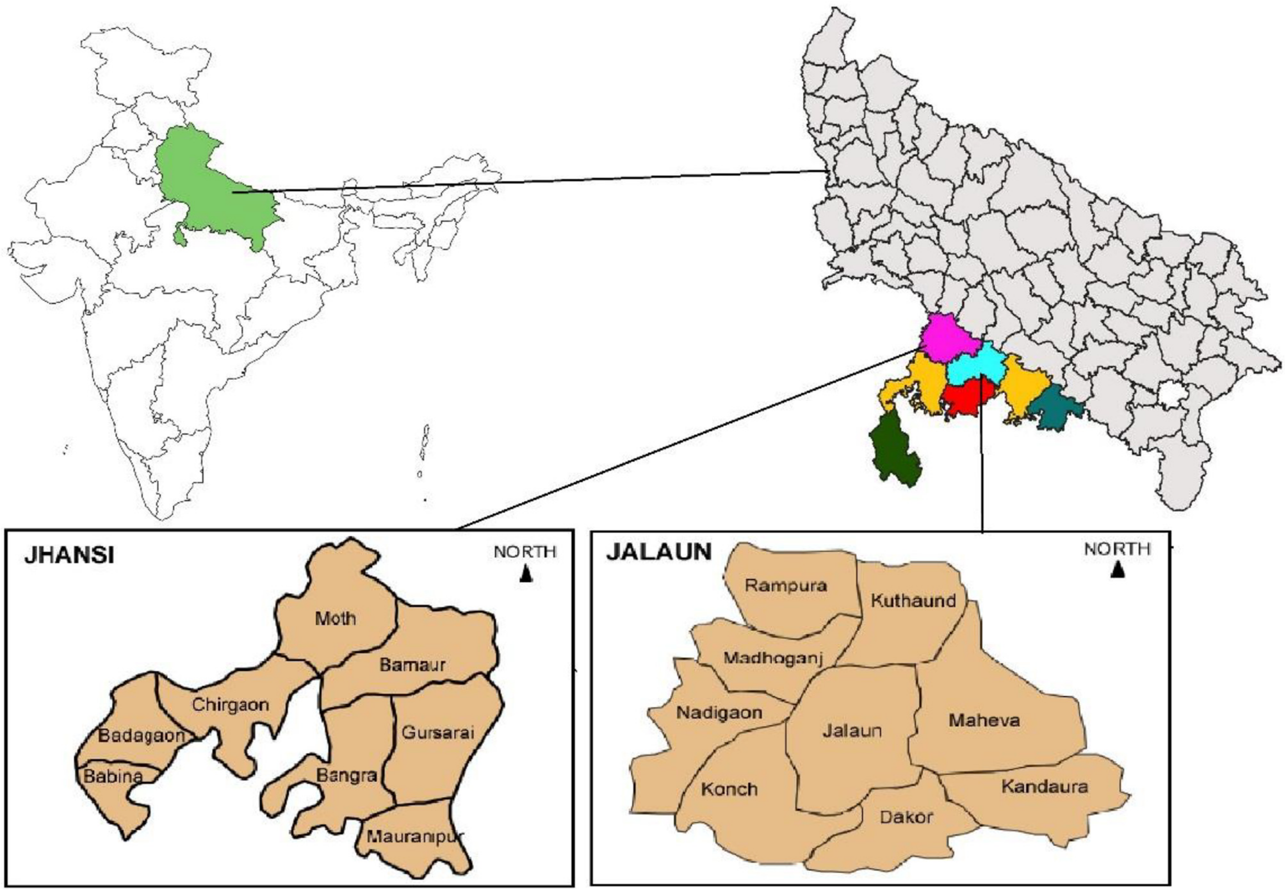

Fig. 2. Map of the Study Area. Source: Author's preparation.

Table 3
Socioeconomic status of Bundelkhand Region, Uttar Pradesh and India.

Indicators	Bundelkhand	Uttar Pradesh	India
Dependency rate (%)	79.00	77.80	55.51
Workforce participation rate (%)	39.50	32.90	55.90
Literacy rate (%)	55.80	57.30	74.01
Sex ratio (per 1000 Men)	877	912	943
Population density (per Square Kilometre)	329	829	416
Crude birth rate (%)	30.50	18.10	19.00
Crude death rate (%)	9.60	3.70	7.30
Per capita income* (in Indian Rupees)	19, 00	43, 86	86, 45
Poverty rate (%)	37.38	29.43	23.60
Marginal farmers (%)	88.62	80.18	86.20
Population rely on forest for cooking (%)	88.64	85.24	81.72
Population drinking water (%)	97.86	98.18	99.14
Female- headed households (%)	36.41	11.15	12.97
Population access to Govt. medical facility (%)	40.69	44.54	49.60
Population having all seasonal houses (%)	70.64	75.53	60.92
Population having toilet facility (%)	36.45	39.20	51.77
Population having electricity connection (%)	80.10	91.78	89.70

Source: Census, 2011. Note: *related to year 2011–12; One US$ = 69.49 Indian Rupees (INR).

variables X_1, X_2 of the term.

$$L_i = In\frac{P_i}{1-P_i} = Z_i = B_0 + B_1X_1 + B_2XB_2 + \cdots\cdots..B_nX_n$$

That is L; the log of the odds ratio is not only linear in $X_i$but also linear in the parameters. Where, L = logit model, P = is the probability of using adaptation strategies. Denote as

$$P = \frac{1}{1+e^{-2}} = \frac{e^z}{1+e^z}$$

where,

$$Z = B_0 + B_1X_1 + B_2X_2 + \cdots\cdots.B_nX_n$$

Therefore, the probability of not using adaptation strategies is:

$$1 - P = \frac{1}{1+e^{-2}}\frac{P}{1-P} = \frac{1+e^z}{1+e^z}$$

Now, P/(1 − P) is simply the odds ratio in favour of using adaptation strategies i.e. the ratio of the probability that farmer will use adaptation strategies to cushion the effect of climate change to the probability that he/she will not.

Thus, if P = 0.9, it means that odds are 0 to 1 in favour of using adaptation strategies. Therefore, if P goes from 0 to 1 (that is, as z varies from $-X_i to + X_i$) the logit, L goes from −X to +X. Although the probability lies between 0 and 1, the logit is not so bounded. Finally, the study hypothesized that there are different factors affecting farmers' decisions in applying adaptive strategies to climate change in agricultural production (Table 4).

Data were cleaned, coded, and analyzed in the STATA statistical software version 13. Descriptive statistics have been used to understand the socio-economic dimensions of surveyed farmers. The coefficients in the binary logistic regression (Multi-criteria analysis) were estimated using the maximum likelihood estimation method. Description of variables that have been used for multi-criteria analysis (MCA) mentioned in Table 4.

Table 4
Description of the dependent and explanatory variables.

Dependent variables	Mean	SD	Description
Cropping pattern change	0.21	0.03	Categorical (Yes = 1, No = 0)
Switch to non-farm occupation	0.39	0.06	Categorical (Yes = 1, No = 0)
Improved irrigation facilities	1.76	0.10	Categorical (Yes = 1, No = 0)
Use of early maturing varieties	0.76	0.07	Categorical (Yes = 1, No = 0)
Use of less water consuming crops	0.86	0.07	Categorical (Yes = 1, No = 0)
Explanatory Variables			
Education	0.73	0.01	Categorical (Below secondary = 0,above = 1)
Above poverty line (APL)	1.42	0.06	Categorical (Yes = 1, No = 0)
@Rainfall	0.85	0.08	Categorical (Yes = 1, No = 0)
#Temperature	0.76	0.07	Categorical (Yes = 1, No = 0)
Land size	1.90	0.12	Continuous (in acre)
$Agriculture credit	0.45	0.09	Categorical (Yes = 1, No = 0)
&Information of climate	0.63	0.10	Categorical (Yes = 1, No = 0)
*Crop insurance	0.52	0.08	Categorical (Yes = 1, No = 0)
Irrigated area	0.63	0.10	Categorical (Yes = 1, No = 0)
Social group	0.52	0.08	Categorical (Backward social groups = 1, No = 0
All seasonal approach road	0.45	0.09	Categorical (Yes = 1, No = 0)
Membership of self-help group	0.63	0.10	Categorical (Yes = 1, No = 0)
Participation in training programme	0.45	0.09	Categorical (Yes = 1, No = 0)

Source: Estimated from field survey data, 2017. Note: @Rainfall indicates that farmer perceived rainfall has declined. #Temperature indicates that farmer perceived temperature has increased. $Agricultural credit indicated that a farmer has access to institutional credit. &Information of climate indicates that a farmer has access to climate information regularly. *Crop Insurance indicates that farmer has insured their crop through weather-based crop insurance.

3. Results

3.1. Socio-economic characteristics of the surveyed households

The socio-economic features of sample households reflect the backwardness of the region compared to that of national level. The literacy rate is relatively lower i.e. 50.24%, 49.76% in Jalaun and Jhansi, respectively, as compared to national average (Table 5). Nearly 50% of the total workforce is unemployed. Further, the mean annual income of the household is also low and widely varied. The mean land size of farm-households in these two districts (0.26 ha and 0.35 ha, respectively) is also low as compared to the national level (1.18 ha). Nearly 15% of the population belongs to scheduled castes and scheduled tribes (backward social groups in India) categories.

Furthermore, 35% of Jalaun and 20% of households in Jhansi don't have an electricity connection. Nearly 50% & 40% of sample population don't have sanitation and drinking facilities within the premises of home. Nearly 30% of the population is living under extreme poverty. In totality, the results show that the majority of the sample household is deprived of basic amenities.

Table 5
Socio-economic characteristics of surveyed farm households.

Characteristics	Jalaun	Jhansi	India
Female (in % to total population)	44.74	44.18	48.00
Illiterate population (in % to total population)	50.24	49.76	74.01
Unemployed population (in % to total population)	49.94	50.06	44.10
Mean Income (in US $)	334	374	2198
Mean land size (in acre)	0.26	0.35	1.18
Mean age of the household (in the year)	31.36	30.04	29.00
Scheduled caste population (in % to total population)	13.82	7.81	16.60
Scheduled tribe population (in % to total population)	2.80	5.10	8.60
Religion (in % to Hindu population)	84.21	84.37	79.80
Marital Status (in % of married to total family members)	52.39	53.32	45.60
Households having electricity connection (in %)	65.00	80.00	89.70
Households having sanitation facility (in %)	57.00	51.00	51.77
Households using improved drinking water facility (in %)	61.00	60.00	99.14
Households below poverty line (in %)	29.00	26.00	23.60

Source: Field survey data, 2017, Census, 2011, Agricultural Census, 2015–16 and NFHS, 2015–16. Note: One US$ = 69.49 Indian Rupees (INR).

3.2. Farmer's perception of climate change

Analysis of farmer's perception of climate change is a prerequisite for assessing adaptation. The literature on climate change perception has clearly identified the importance of timing and types of climate change instances, which usually farmers observe and utilize in framing their perceptions. Therefore, this study purposefully distinguishes normal and extreme changes in weather observed by farmers over a long term period. Weather extremes are uncertain, and farmers are required to act instantaneously to avoid losses. Decision making by farmers under such circumstances is quite difficult as the time lag between gatherings and processing information into the decision to adopt is quite small.

The study results indicate that 67% of farm households (134 out of 200) perceived changes in rainfall level (Fig. 3). Most of farmers (94 & 93%) perceived that in the past one decade, the summers have become hotter and frequency of drought has increased. About 95% of farmers realized that the groundwater level has declined. Study findings are in the line of Smit et al. (1997); Bryant et al. (2000); Bryan et al. (2009); Hansen et al. (2004). These studies have pointed out that farmer's perception of climate change depends on their recent and past experiences. These results are also in line with Indian Meteorological Department (IMD, 2017) temperature record for the Bundelkhand region, which suggests a significant increase in annual temperature by about 0.01 °C per year during 1951 to 2017. In the case of rainfall, the actual annual rainfall trend during 1951–2017 showed a decline of 1.41 mm per year. The summer and winter rainfall also show sharp decline-annually of about −0.59 mm and about −0.06 mm respectively.

The qualitative analysis has also been undertaken. Farmers reported that droughts have dual impacts on livelihoods. The majority of farm-families in surveyed villages had lost either their crops or cattle or both that was the first line of deference to deal with climate change. As the villagers themselves struggle to live during crisis time, the survival of cattle is the last thing in their minds. Farmers belonging to Amra village of Jhansi district had 1500 livestock population, as against 8000 livestock population four years ago (i.e., 2012–13). Lack of compensation for cattle death, livestock has not been considered as a resource in the policy of State. Farmers perceive that the government has not made any visible and significant provision for livestock survival during extreme climatic variability, making them dissuade from rearing livestock as an enterprise.

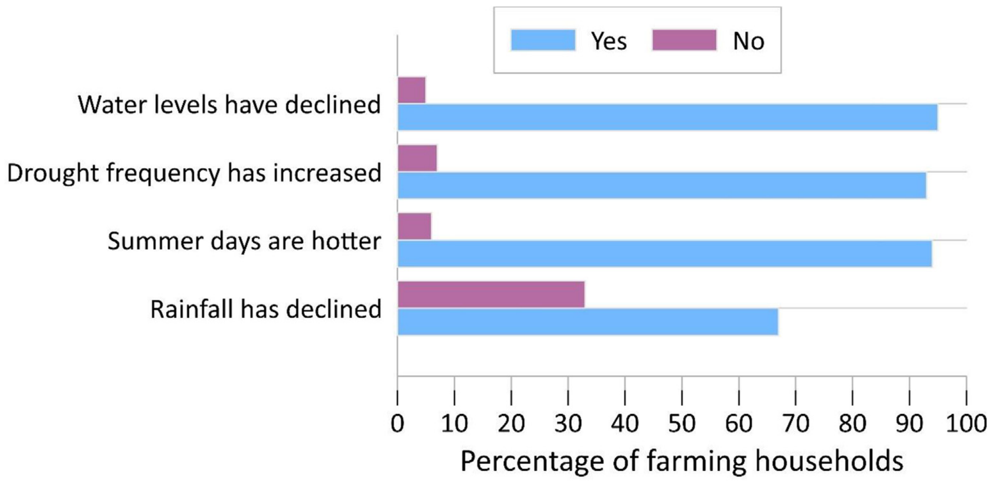

Fig. 3. Farmers' perception of climate change (in %). *Source*: Field survey data, 2017.

3.3. Adaptation strategies in rainfed agriculture

Agricultural adaptation varies by time (short-term or long-term), scale (farm-level, national-level) and types. For instance, Smit and Skinner (2002) have categorized farm-level adaptations into three main categories, i.e., changes in farm management practices, farm-level technological developments, and financial management for farm protection. Based on these broad categories, studies have identified several adaptation strategies. For example, at micro-level, changes in farm management practices involve crop diversification, shortening or lengthening of growing seasons, changing planting dates, altering land under cultivation, increase/decrease use of irrigation; technological developments may include using new crop varieties, adopting soil and water conservation techniques, adopting weather information and forecasts; and financial management for farm protection may involve switching from farm to non-farm activities, ensuring crops, migration to urban areas for livelihood (Nhemachena and Hassan, 2007; Kurukulasuriya and Mendelsohn, 2006; Gbetibouo and Ringler, 2009; Below et al., 2012; Deressa et al., 2009; Hisali et al., 2011; Maddison, 2007). Farmer's actual adaptation is often driven by their capacities to predict climate, and adaptation decisions are mainly influenced by the local social, cultural, and political conditions. Farmers' adaptation at scale involves adjustment decisions usually taken in short time and are mostly based on onset of seasonal climate.

For assessing the adaptation strategies of farmers in the study area, the study identified eight (8) different adaptation options (Fig. 4). Farmers' adaptation choices were ascertained by a detailed field survey on adaptation strategies adopted by farmers. As far as the choice of adaptation strategies is concerned, Fig. 4 displays the options of adaptation strategies for perceived changes in temperature and precipitation. It is important to highlight that the choices of adaptation strategies are not mutually exclusive. Hence, farmers resorted to choosing more than one strategy at any given time. For instance, farmers may change cropping pattern and crop varieties, which may require an increase/decrease of irrigation. Farmers may also decide to change their occupation (switch to non-farm income) for earning additional income based on their livelihood, which is subject to frequent changes. Also, apart from some usual on-farm changes, farmer may also decide to insure their crop in the event of crop failure (i.e., crop insurance).

The evidence from the study results revealed that above 60% of farmers planted eucalyptus, citrus, and mangoes trees surrounding their fields and diversified their cropping pattern in favour of low water requiring crops (Fig. 4). As Bundelkhand region is a dry one, therefore, irrigation has a potential impact on farm returns. More than 40% of sample households have increased irrigation coverage through rainwater harvesting and growing less water requiring varieties of Jowar (Pusa Chari- 615), Bajra (APFB-2), Pulses (PUSA Arhar- 16), and Oilseeds (RCC- 4). Few farm-households opined that by increasing inputs, the productivity of crops could be increased and hence nearly 35% of households increased the use of bio-pesticides and fertilizers. About one-fifth (19.5%) of farm households were engaged themselves in non-farm activities, to moderate the degree of exposure from climate change.

3.4. Determinants of adaptation strategies: evidence from multi-criteria analysis

Multi-criteria analysis (MCA) has been used to identify factors determining farmers' decision in adapting to climate change effects. The method is best to predict the probability that a farmer will adopt a suitable strategy to climate change in a bid to mitigating its effects. The decision of farmers is a discrete value (1, 0). One (1) denotes that farmers who adapted to climate change, while zero (0) denote farmers who did not adapt to climate change. This study identified eight major adaptation strategies. However, after diagnostic tests, we find that only five are best fit for our estimation (Fig. 4).

Initially, 13 explanatory variables were included in the model (Table 4). However, after testing for multicollinearity problem using the Pearson's correlation test among the explanatory variables, and only ten (10) explanatory variables were finally included in the empirical model (Table 6). Also, the issue of heteroskedasticity of the model was addressed using the robust standard error procedure. Wooldridge (2013) highlighted that robust standard error could effectively solve heteroskedasticity since it gives relatively accurate P-value to ensure the significance of the model.

Table 6 shows the estimated parameters of the empirical binary logit model. The regression classification table indicated that the MCA predicted about 90% of the responses correctly. The model fits the data at ($p < 0.001$) as indicated by the chi-square (Prob > chi2) goodness of fit statistics. The goodness of fit demonstrated that the variables captured in this study were valid. It explains the factor that determines the willingness of a farmer to adopt any adaptation strategy in dealing with climate change in the study area. Study results also reject the null hypothesis and accept the alternative hypothesis stating a significant relationship between the capture variables and farmers' willingness to adopt an adaption strategy. Determinants are categorized into four main determinants, viz., biophysical, social, economic, and extension services. For instance, biophysical (temperature and rainfall), social (education and land size), economic (income, APL and irrigated area), and extension services (agriculture credit, information on climate and access to crop insurance).

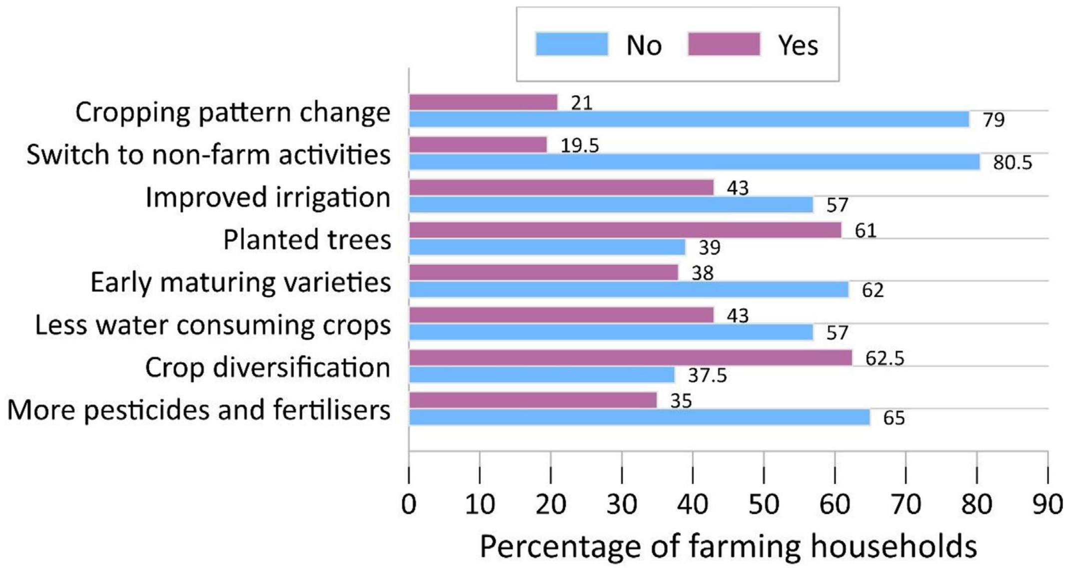

Fig. 4. Adaptation strategies adopted by surveyed farm households. Source: Field survey data, 2017.

3.4.1. *Biophysical*

This study has considered farmers' perception of declining rainfall and increasing temperature over the past decade as biophysical determinants of identified adaptation strategies (Table 6). Rainfall and temperature are significantly and positively influence the farmers' probabilities of cropping pattern change, switch to non-farm, improved irrigation, early maturing varieties, and less water consuming crops. In other words, a farmer who perceived that rainfall has declined and temperature is increasing in past decade, is likely to adopt different adaptation strategies. For instance, the calculated odds ratio shows that there is a 3.3 times higher probability of improving irrigation infrastructure once farmers perceived that temperature is increasing.

3.4.2. *Social*

The present study has considered education and land size as social determinants for identified adaptation strategies. Education level significantly and positively influences the farmers' probabilities to change cropping pattern, switch to non-farm, improved irrigation, early maturing varieties, and low water crops. Farmers who attained higher education (above secondary level) are more likely to adapt climate change by switching to different adaptation strategies. Study findings are in the line of Maddision's (2006) and Nhemachena and Hassan (2007) and Kibue et al. (2016). These studies suggested that educated farmers have more knowledge and information about climate change and agronomic practices that they can use of. More specifically, households with larger farm size and family head having higher

Table 6
Determinants of adaptation strategies.

	Independent Variables	Cropping pattern change	Switch to non-farm	Improved irrigation	Early maturing varieties	Less water requiringcrops
Biophysical	Rainfall	0.476*	1.009*	0.618*	0.155**	0.198**
		(1.609)	(2.743)	(0.539)	(0.856)	(1.219)
	Temperature	1.441*	1.452*	1.200*	0.254*	0.555**
		(4.224)	(0.234)	(3.319)	(1.289)	(1.742)
Social	Education	0.208*	0.020**	0.154*(1.167)	0.639**	0.333*
		(0.812)	(0.980)		(0.528)	(0.716)
	Land Size	0.274*	0.009*	0.244**	0.056*	0.005*
		(1.315)	(1.009)	(1.000)	(1.058)	(1.005)
Economic	Income	−0.632*	−0.082*	0.504	0.197*	0.846*
		(1.000)	(1.000	(1.000)	(1.000)	(1.000)
	APL	0.632*	0.189**	−0.912*	0.422**	0.475*
		(1.881)	(1.209)	(0.402)	(1.525)	(0.622)
	Irrigated Area	−0.404**	−0.464*	–	–	–
		(0.668)	(0.629)			
Extension Services	Agriculture Credit	1.307*	−1.320*	0.701*	0.616*	0.229**
		(3.695)	(0.267)	(2.016)	(0.540)	(1.257)
	Information of Climate	0.162*	0.595*	1.230*	0.314**	0.126*
		(1.176)	(0.551)	(3.420)	(0.730)	(0.882)
	Crop Insurance	1.441*	−1.405*	0.586**	0.254*	0.555**
		(1.881)	(4.077)	(0.557)	(1.000)	(1.219)
	Constant	−1.616*	−0.087*	−0.294-	−0.420*	−0.348**
		(0.199)	(0.917)	(0.746)	(0.657)	(0.706)
	LR chi^2	24.96	28.31	38.59	13.26	5.18
	Prob > chi^2	0.0030	0.0016	0.0019	0.0031	0.0086
	Pseudo R^2	0.9213	0.9035	0.9121	0.9307	0.9492
	Log likelihood	−69.993	−84.521	−116.432	−124.239	−132.374
	No. Observation	200	200	200	200	200

Source: Estimated from field survey data, 2017. Note *, **, and *** indicate 1, 5, 10 percent level of significance, respectively, and NS indicates non-significant. Values in parentheses are odd ratios.

Table 7
Change in income after the adoption of adaptation strategy (In US$).

Adaptation Strategy/ Change in Income	Pre-Adaptation per capita income	Post- adaptation per capita income	Change (%)
Cropping pattern change	352	452	28
Non-farm activities	259	347	34
Improved irrigation	247	444	80
Planted trees	319	479	50
Early maturing varieties	194	339	75
Less water-consuming varieties	235	391	67
Crop diversification	244	371	52
More pesticides and fertilizers consumption	262	344	31

Source: Field survey data, 2017. Note: One US$ = 69.49 Indian Rupees (INR).

educational attainment are more likely to adopt identified adaptation strategies.

3.4.3. Economic

Farm income is the other key factor and households living above the poverty line (APL) and have irrigated area are more likely to adapt climate management strategies (Table 6). The MCA results show that income has significantly and positively influenced the farmers' probabilities of improved irrigation, early maturing varieties (HS 542 Pusa Kiran) and less water consuming crops, i.e., wheat (Pusa Chari- 615), Bajra (APFB-2), pulses (PUSA Arhar- 16), and oilseeds (RCC- 4), and on the other hand, income has significantly and negatively influenced farmers' probabilities of cropping pattern change and switch to non-farm activity.

Households living above the poverty line (APL) have significantly and positively influenced the farmers' probabilities of cropping pattern change, switch to non-farm income, early maturing varieties and less water consuming crops, and on the other hand, APL has significantly and negatively influenced the farmers' probabilities of improved irrigational infrastructure.

Irrigated area is the other main determinant of climate adaptation strategy in the dry region, i.e., Bundelkhand region. Study findings reveal that the irrigated area has significantly and negatively influenced the farmers' probabilities of a cropping pattern change and switch to non-farm income. Assured access of irrigation throughout cropping season has restricted farmers to change cropping pattern (i.e., farmers grow wheat in Rabi for food consumption) and switch to non-farm income. The outcome of assured and subsidized irrigation facilities has resulted in higher production.

3.4.4. Extension services

This study has perceived agricultural credit, information of climate, and crop insurance (extension services) as determinants of identified adaptation strategies (Table 6). The MCA results show that agricultural credit has significantly and positively influenced the farmers' behaviour of improved irrigation, early maturing varieties and less water consuming crops, and on the other hand, significantly and negatively influences the farmers' and going for a cropping pattern change and switch to nonfarm income, respectively. In other words, households that had access to available credit are more likely to adapted to climate change in their agricultural production by improving irrigation, grown early maturing and less water consuming crop varieties. Sample households are marginal farmers who depend on farm income to meet household challenges. Farmers with access to credit have a higher chance of adapting to changing climatic conditions. Access to affordable credit increases the financial resources of farmers and their ability to meet transaction costs associated with the adaptation option.

Knowledgeable, educated and experienced farmers always try to maximize the agricultural production by using all available resources, including weather forecasts to combat climate change. The MCA results show that farmers having information about weather are likely to adapt various adaptation strategies. Once they got information on seasonal climate variability trends such as drought in the season, then they immediately start conserving water resources (improving irrigation). The calculated odds ratio shows that there is a 3.4 times higher probability of improving irrigation infrastructure, if farmers have information on seasonal climate variability (Table 6).

In uncertain adverse climatic conditions for agriculture, crop insurance can buffer the financial implications of unexpected crop failure following extreme events such as drought (Moschini and Hennessy, 2001). Financial products can be used to counter the over or under-provision of ecosystem services. Study findings reveal that crop insurance has significantly and positively influenced the farmers' probabilities of cropping pattern change, improved irrigation, and use of early maturing and less water consuming crop varieties, and on the other hand significantly and negatively influenced the farmers' probabilities of switching towards nonfarm income. In other words, households having crop insurance coverage are more likely to change cropping patterns, improved irrigation, and use of early maturing and less water consuming crop varieties.

3.5. Changes in income after adoption of the coherent adaptation strategy

The outcome of adaptation strategy adapted has been quantified through change in income. Identified adaptation strategies are the win-win options. After adapting early maturing varieties and less water consuming crop varieties, farmer's income has increased by 75 and 67%, respectively, whereas those who improved irrigation facility, received income up to 80% (Table 7).

4. Discussion

4.1. Farmers' perception and climate change adaptation

Study findings reveal that farmers are highly aware of climate change and its adverse effect on agriculture and livelihoods. Hence, farmers firstly identified the main barriers and then started to adjust resources, communicated, and shared their indigenous expertise to cope up with changing climate. The majority of farmers believed that lower livelihood status (least basic amenities) and fewer employment opportunities in the nonfarm sectors are major barriers. Farmers have adopted the least investment and subsidized adaptations strategies, viz., cropping pattern change, improved irrigation, less water consuming crop varieties. During survey, farmers shared their experience and mentioned that drought is now common phenomena in the region. Therefore, adjusting farming system accordingly (resilience) is a common phenomenon. Farmers seemed fully aware of the extension services provided by the government institutions, viz., crop weather insurance, regional weather forecast report, balance use fertilizers, and water through canal irrigation.

4.2. Determinants of climate change adaptation

Identification of determinants of climate change adaptation strategies was the main focus of this paper. It was observed that biophysical, social, and extension services were the main determinants influencing farmers to adopt identified adaptation strategies. Farmers are utilizing their traditional knowledge (biophysical determinants) of changing climate (i.e., farmers' perception of decline in rainfall and increase in temperature) to protect the farming system and livelihoods. Well educated farmers with large land size (social determinants) are found to be the front runners in climate change adaptation. They are wisely and quickly adjusting their farming system by changing cropping patterns, using early maturing & less water crop varieties.

While institutional credit and weather-based crop insurance (extension services determinants) protect them from the adverse impacts of calamities. Microfinance can reduce vulnerability through *ex-ante* risk reduction via livelihood diversification, *ex-post* risk mitigation via savings and insurance, and finally risk coping via credit. In the absence of insurance, farmers have to rely on coping mechanisms such as withdrawing savings, accessing loans, selling assets, or reducing expenditure (Fenton et al., 2015). Risk-averse farmers that can't use these *ex-post* coping mechanisms have been found to sacrifice total income for income stability. Pierro and Desai (2008) found the weather-based insurance using physical triggers as proxy mechanisms have been more successful than traditional crop insurance in reducing transaction costs, pay-out times, disputes, and asymmetric information problem. Moreover, the findings are broadly in line with other studies on the subject (Moschini and Hennessy, 2001; Maddision, 2006, 2007; Nhemachena and Hassan, 2007; Deressa et al., 2009; Hisali et al., 2011; Kibue et al., 2016).

5. Conclusions and policy implications

The paper provides understanding of micro-level adaptation decisions adopted by sample farmers. As a process of involving perceptions of climate change, farmers utilized their leanings from past experiences in dealing with climate uncertainties, risk, and hazard. Their interdependence on fellow farmers (agents) through social relationships and the institutional mechanisms in the form of extension services (credit and insurance) helped in undertaking adaptation actions. The study using secondary (Scopus database) and survey data analysis finds that the process in itself, along with socioeconomic endowments of the surveyed households, are the key enablers of farmers' adaptive capacity.

The paper asserts that most of the farmers perceived changes in temperature, precipitation level and drought as the most profound climate condition which impacts their livelihoods. Farmers primarily rely on their climate predictions i.e., traditional knowledge and information among the peer network. The vital set of adaptation strategies that farmers in Bundelkhand region often cater to for seasonal adaptation includes irrigation, changing crop variety, switch to non-farm income, and changes their cropping pattern.

The results provide useful guideline towards identifying region-specific adaptation strategies and enable policy intervention in strengthening other non-farm specific adaptation options like crop insurance schemes and availability of non-climate sensitive jobs. Policy intervention should prioritize eliminating asymmetry in information and communications. Enhancing institutional capacities to forecast weather in small geographic regions accurately and authorizing accountability of meteorological department imperative. The government can work towards building a common platform for scientific exchange of district or plot level information among farmers, seed and machinery retailers, fertilizer suppliers, banks, and insurance companies. It can help in collaborative decision-making towards climate-resilient and sustainable agriculture solutions involving all related stakeholders with adequate interventions from policy agents, i.e., government, private agencies, and non-government organizations (NGOs). There is also a need to customize extension services for smallholders to improve the adaptation rate and ensure long-term impact. Further, to potentially utilize the benefits of farmer's social networks, it is necessary to enhance agricultural livelihood through community institutions.

Finally, the present study synergies between macro and micro-level climate change adaptation and helps in mainstreaming of climate-smart adaptation strategies in rainfed areas. The results of this study, however, needs to be interpreted with caution because of certain limitations. First, the present study has collected and reviewed papers which published only in the 'Scopus database', excluding other online databases and also limited the study period between 2007 and 2019. Due to this, it may be possible that this study may be excluded potential and relevant studies on climate change adaptations. Second, this study uses small sample size, i.e.200 samples from selected two districts of Bundelkhand region, excluded 11 districts. Therefore, it would be difficult to generalize the findings in the context of the drought-prone regions of India. Adaptations are varying region-to-region and village-to-village; therefore, it may be possible to miss other relevant farm-level effective adaptation measures, which would otherwise have been adopted by farmers. Third, this study has taken only 10 determinants of climate change adaptation, excluding other determinants. Therefore, results of this study are only valid, if these variables are included into estimation, otherwise results would be biased. Finally, Indian farming society has complex and divided into castes, classes, religions systems which varies from region-to-region and even household-to-households. Hence, it generates scope for future research on farmers' perception of climate change, determinants of climate change adaptation.

Declaration for language revision

The author has thoroughly revised the manuscript, including English editing so that this manuscript meets the standards of the Ecological indicators journal.

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Appendix A. Supplementary data

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Bridging the gap between biophysical and social vulnerability in rural India: a community livelihood vulnerability approach

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RESEARCH ARTICLE

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ABSTRACT

This study of the nature and extent of livelihood vulnerability of farm households in the Bundelkhand region of Uttar Pradesh, India, involved the computation of livelihood vulnerability indices and indices of exposure, sensitivity and adaptive capacity for different social communities. The empirical findings reveal that farmers belonging to Scheduled Tribes (ST) communities were relatively highly exposed and sensitive to climate change and least able to adapt. In this light, several policy recommendations are proposed to improve the livelihood security of vulnerable groups.

ARTICLE HISTORY

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KEYWORDS

livelihood vulnerability, farmers' perceptions, local adaptation strategies, climate change, regional exposure, Bundelkhand region, India

摘要

缩小印度农村生物物理和社会脆弱性之间的差距：应对社区生计脆弱性的方法. *Area Development and Policy*. 本文对于印度北方邦邦德尔汗地区农户生计脆弱性的性质和程度进行了研究，研究包括生计脆弱性指标的计算以及不同社会群体的暴露、敏感性和适应能力指数的计算。实证结果表明，住在ST社区的农民受气候变化影响较大，对气候变化敏感，适应能力较差。鉴于此，本文提出了一系列改善弱势群体生计安全的政策建议。

关键词

生计脆弱性, 农民的看法, 本地适应策略, 气候变化, 地区暴露, 邦德尔汗地区, 印度

RESUMEN

Tender puentes entre la vulnerabilidad biofísica y social en la India rural: un enfoque sobre la vulnerabilidad de los medios de subsistencia en la comunidad. *Area Development and Policy*. En este estudio sobre el carácter y la magnitud de la vulnerabilidad de los medios de subsistencia de los hogares agrícolas en la región de Bundelkhand de Uttar Pradesh India se analiza la computación de los índices de vulnerabilidad de los medios de subsistencia y los índices de exposición sensibilidad y capacidad de adaptación para las diferentes comunidades sociales. Los resultados empíricos indican que los agricultores que pertenecen a las comunidades de tribus reconocidas están relativamente más expuestos y sensibles al cambio climático

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y presentan menos capacidad de adaptación. En este sentido se proponen una serie de recomendaciones políticas para mejorar la seguridad de los medios de subsistencia de los grupos vulnerables

PALABRAS CLAVE
vulnerabilidad de los medios de subsistencia, percepciones de los agricultores, estrategias de adaptación local, cambio climático, exposición regional, región de Bundelkhand, India

АННОТАЦИЯ
Преодоление разрыва между биофизической и социальной уязвимостью в сельских районах Индии: подход к уязвимости жизнеобеспечения сообществ. *Area Development and Policy*. Это исследование характера и степени уязвимости жизнеобеспечения фермерских хозяйств в районе Бундельканд штата Уттар-Прадеш, Индия, включает расчет индексов уязвимости жизнеобеспечения и индексов подверженности, чувствительности и адаптационных возможностей для различных социальных сообществ. Эмпирические данные показали, что фермеры, принадлежащие к низшим кастам (scheduled castes), были относительно высоко подвержены воздействию и чувствительны к изменению климата и наименее способны адаптироваться. В этой связи предлагается ряд политических рекомендаций, направленных на улучшение условий жизни уязвимых групп населения.

КЛЮЧЕВЫЕ СЛОВА
уязвимость средств к существованию, восприятие фермеров, местные стратегии адаптации, изменение климата, региональное воздействие, регион Бундельканд, Индия

INTRODUCTION

At the 24th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCC-COP16), a consensus has emerged on the need to devise methods to identify the population most vulnerable to climate risk (UNFCC, 2018). The conference concluded that countries located near to low and middle latitudes with low per capita income, poor infrastructure (such as roads, sanitation and housing), lack of an advanced system of weather forecasting, and low awareness of climate change are highly vulnerable. The report also stated that South Asian countries, including India, are more vulnerable to climate change owing to high population density, which is greatly exposed to climatic risks such as floods, droughts, storms, coastal inundation and sea-level rise (Krishnamurthy, Lewis, & Choularton, 2014).

In India, agriculture is highly vulnerable to risks and uncertainties, and marginal and small farmers among all farm groups are most vulnerable to the effects of climatic variability (Kelkar, Narula, Sharma, & Chandna, 2008; Pandey & Jha, 2012; Sudha Rani, Satyanarayana, & Bhaskaran, 2015). The impact of extreme weather events and natural resources on which farmers are dependent aggravates their vulnerability (Singh et al., 2017). It has been noted that climate change will further intensify and smallholding farmers (> 80%) will be most affected, as they entirely rely on climate-sensitive livelihoods (from agriculture) and have a low adaptive capacity (Chingala, Mapiye, Raffrenato, Hoffman, & Dzama, 2017). In this situation, climate risk management strategies, capable of helping farm households improve farm productivity and livelihood security are vital.

The literature on vulnerability assessment identifies social and biophysical vulnerability (Qing & Maria, 2018). Biophysical vulnerability refers to the impact of hazards such as rainfall, floods, droughts and cyclones, and the damage they cause. Social vulnerability deals not with hazard severity or probability of occurrence but with the social properties of a system such as poverty, income inequality, migration and unemployment (Brooks, 2003) that make it more vulnerable to certain types of a hazard than others. For instance, the quality of housing might be an important determinant of community (social) vulnerability to floods or windstorms, but it is less likely to influence its vulnerability to drought.

Past vulnerability studies have assessed biophysical vulnerability (Adger, 1999; Adger & Kelly, 1999; Allen, 2003) and social vulnerability of single regions and have compared agro-ecological regions (Adger & Kelly, 1999; Blaikie, Cannon, Davis, & Wisner, 1994; Cross, 2001).

In order to understand household well-being, an integrated livelihood approach examining how households allocate their assets has been proposed (Qing & Maria, 2018). This approach provides useful insights into household exposure, sensitivity and resistance to climate-related impacts (IPCC, 2014). Exposure and vulnerability are related. If resources and technologies are not sufficient to cope with risk, the anticipation of risk, a willingness to change behaviour and an ability to mobilize resources can contribute to adaptation and resistance (Eakin, Lemos, & Nelson, 2014).

The aim of this study is to employ a community livelihood vulnerability approach (CLVA) to assess the biophysical and social livelihood vulnerability of mainstream social communities of India and the factors contributing to it. This index is employed at a community or household level to identify and evaluate who within a community is more vulnerable and the context and region-specific risks.

The paper is organized as follows. The next section outlines the linkages between biophysical and social vulnerability and the livelihood vulnerability approach. The third section introduces the study area, sampling framework and methods used to examine livelihood vulnerability. The fourth section outlines the results. The final section concludes.

BACKGROUND AND METHODS

Study area

The study was undertaken in the Bundelkhand region of Uttar Pradesh (UP) in India. UP plays a vital role in India's food and nutritional security by contributing 17.83% of the country's total food grain output in 2016–17 (GoI, 2017). Geographically, UP is divided into four economic regions: western, central, eastern and Bundelkhand. This study was undertaken in two districts of Bundelkhand region: Jalaun and Jhansi, due to the preponderance of droughts in the region (Figure 1).

Historically, Bundelkhand has been more vulnerable to climate change than other regions of UP. It experienced drought every 16th year during the 18th and 19th centuries. The incidence of droughts increased threefold between 1968 and 1992, and is now a recurrent annual phenomenon (GoI, 2017). Average annual rainfall was below average during 2004–17 (Figure 2). Farmers mainly grow wheat, soybean, tur, rapeseed, paddy, gram, maize, groundnut, jowar and bajra. The severity of the shortage of rainfall was such that 40% of the net sown area remained fallow, resulting in 30% less in food grains output (NRAA, 2018).

Apart from droughts, variations in temperature are also a cause of household vulnerability. The mean maximum and minimum temperatures increased by 0.28°C during 1969–2017 compared with 1960–90 (Figure 3). A rise in temperature leads to high evapotranspiration, causing a loss to soil moisture and reductions in groundwater recharge and surface water.

Socioeconomic features of Bundelkhand region

Table 1 reports various social indicators for the Bundelkhand region, UP and India. The dependency rate, workforce participation, literacy rate and per capita income are relatively low compared with UP and India. The region also lagged in access to basic amenities, namely

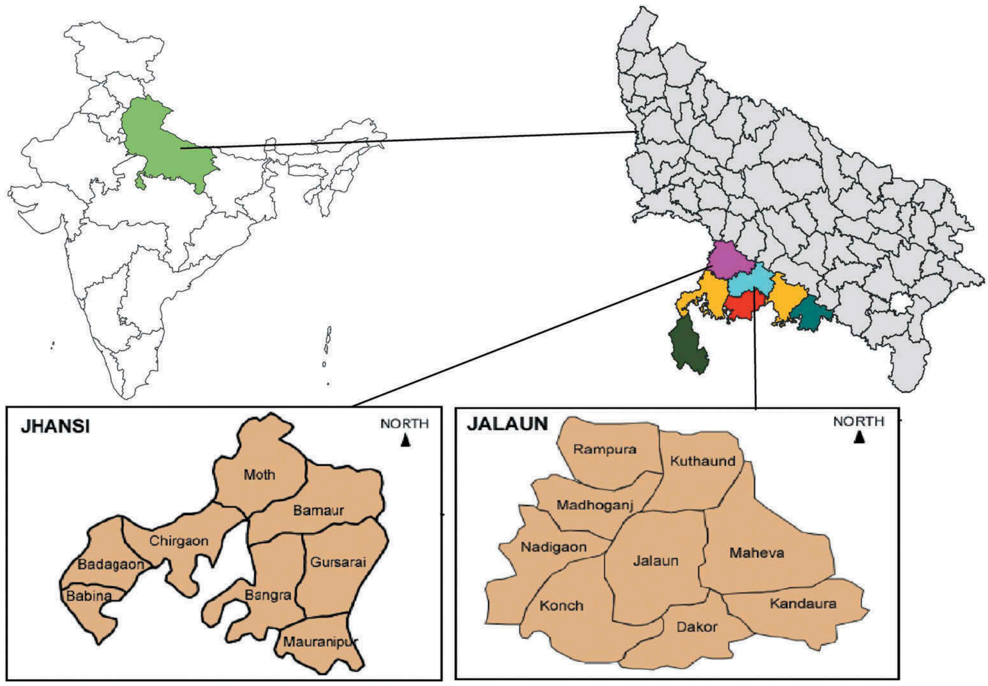

Figure 1. Study area.

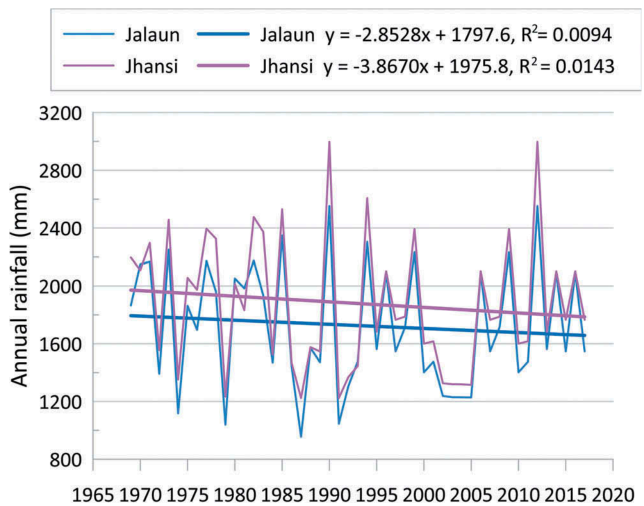

Figure 2. Variability in annual rainfall (mm).

a reliance on forest resources for cooking, drinking water, medical facilities, all seasonal houses, toilet facilities and electricity connection relative to UP and India.

Sampling framework

A multi-stage sampling technique was used to select study sites and households. In the first step, two districts, namely Jhansi and Jalaun, were chosen from thirteen districts in

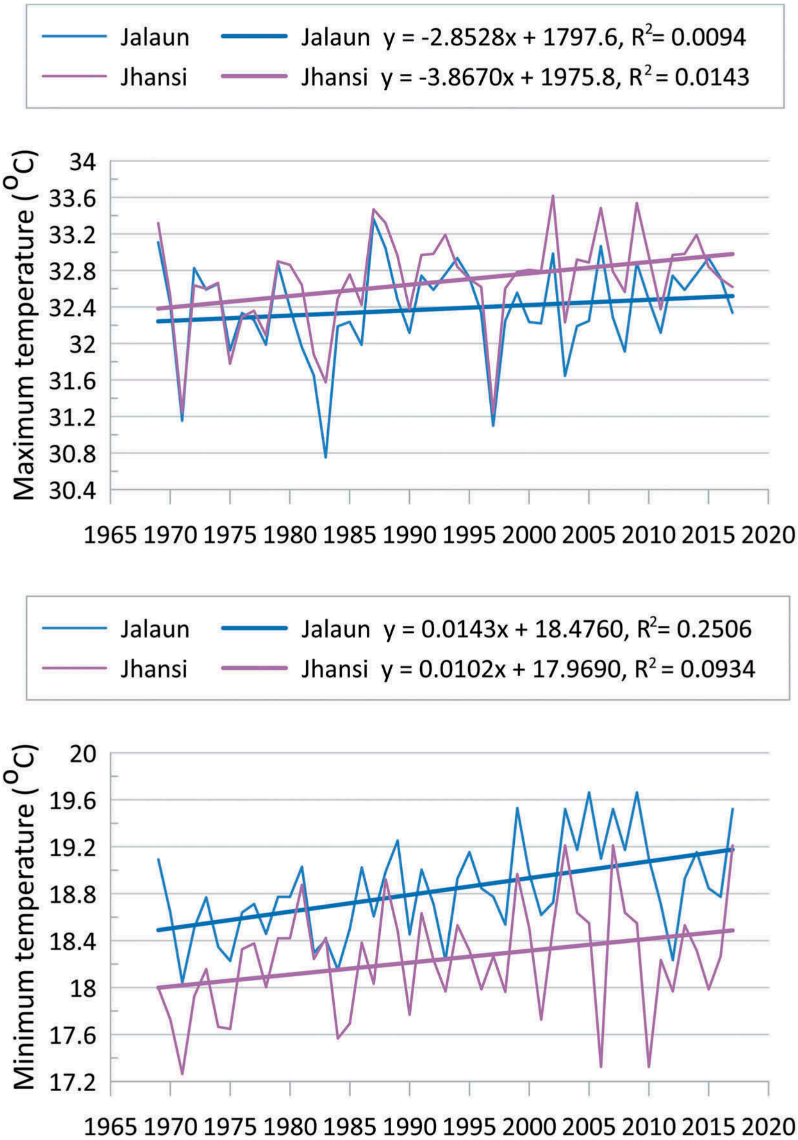

Figure 3. Variability in maximum and minimum temperature (°C).

Bundelkhand. Next, each of the five subdivisions (i.e., *tehsils*) in each district were selected. In the third step, one development block was selected purposively from each *tehsil*. In the fourth step, one village from each selected block was chosen randomly. Finally, 20 households from each village were selected randomly. The result was the selection of two districts, 10 *tehsils*, 10 developmental blocks, 10 villages and 200 farm households. Household farm holdings comprised marginal (< 1.0 ha), small (1–2 ha), semi-medium (2–4 ha), medium (4–10 ha) and large (> 10 ha) farms. The farmers selected comprised 20% of households from each of these farm size categories in the selected villages. A well-structured and pre-tested schedule was used to collect information about the selected farmers' perception of climate change and variability during the past five years and the choice of adaptation strategy. The survey was undertaken during May–June 2017 soon after harvesting of the

Table 1. Socioeconomic status of Bundelkhand region, Uttar Pradesh and India

Indicators	Bundelkhand	Uttar Pradesh	India
Dependency rate (%)	79.00	77.80	55.51
Workforce participation rate (%)	39.50	32.90	55.90
Literacy rate (%)	55.80	57.30	74.01
Sex ratio (per 1000 men)	877	912	943
Population density (per km^2)	329	829	416
Crude birth rate (%)	30.50	18.10	19.00
Crude death rate (%)	9.60	3.70	7.30
Per capita income (Indian rupees)[a]	19,000	43,861	86,454
Poverty rate (%)	37.38	29.43	23.60
Marginal farmers (%)	88.62	80.18	86.20
Population rely on forest for cooking (%)	88.64	85.24	81.72
Population drinking water (%)	97.86	98.18	99.14
Female-headed households (%)	36.41	11.15	12.97
Population access of government medical facility (%)	40.69	44.54	49.60
Population having all seasonal houses (%)	70.64	75.53	60.92
Population having toilet facility (%)	36.45	39.20	51.77
Population having electricity connection (%)	80.10	91.78	89.70

Note: [a]Related to 2011–12; US$1 = 69.49 Indian rupees (INR).
Source: Census, 2011.

winter crop to elicit information on climate-related variables and agricultural extension services. The survey data related to the agricultural year 2016–17 (July–June).

Selection of indicators of exposure, sensitivity and adaptive capacity

As mentioned in the introduction, this research sought to identify three dimensions of vulnerability, namely exposure, sensitivity and adaptive capacity (Table 2).

Exposure refers to the impact of changes in the frequency, intensity/magnitude, duration and nature of climate stress (Adger, 2006). Time series data for 1950–2000 have shown that the monsoon rainfall pattern in India is now less predictable and more intense (Goswami, Venugopal, Sengupta, Madhusoodan, & Prince, 2006). The number of rainy days has declined, and the intensity of heavy and heavier rainfall events has increased. Dry spells in rainfed agriculture, which generally involve 2–4 weeks of no rainfall, have increased and affect critical crop growth stages, causing partial or complete crop failure. Dry spells often occur during every cropping season, while degraded land has added an additional layer of exposure (Gbetibouo & Ringler, 2009b). A region such as Bundelkhand with higher degraded land resources experiences greater adverse impacts of climate change. Agriculture, which is the main source of livelihood for the farmers, is also exposed to widespread warming. Earlier studies have revealed that a 1°C increase in temperature may reduce the average yield of wheat, soybean, mustard, potato and groundnut by 3.7% (Agarwal, 2009; Chattaraj et al., 2014).

Table 2. Selected rational indicators for livelihood vulnerability index

Component	Indicators	Functional relationship with vulnerability index	Source
Exposure	1. HHs feel that rainfall has declined (%) (Rainfall)	Positive	Masud et al. (2017)
	2. HHs perceive that summer days become hotter (%) (Summer Days)	Positive	Shrestha et al. (2017)
	3. HHs perceive that frequencies of droughts have increased (%) (Drought)	Positive	Funk et al. (2019)
	4. HHs perceive that water level continuously has declined (%) (Water level)	Positive	Omerkhil et al. (2020)
Sensitivity	1. HHs using only forest-based energy resources for cooking purposes (%) (Forest)	Positive	
	2. HHs using hand-pump (untreated) water for drinking (%) (Drinking water)	Positive	Miranda et al. (2011)
	3. HHs depends on government sources for irrigation (%) (Irrigation)	Positive	Miranda et al. (2011)
	4. Female-headed households (%) (FHH)	Positive	Abid et al. (2015); Islam et al. (2013)
	5. HHs using 108 free medical facilities (%) (Medical)	Negative	Alam et al. (2017)
	6. HHs do not have toilet facility (%) (Toilet)	Positive	Alam et al. (2017)
	7. HHs do not have all seasonal house (%) (House)	Positive	Alam et al. (2017)
	8. HHs belong to Below Poverty Line category (%) (BPL)	Positive	Rai et al. (2008)
	9. HHs do not have electricity connection (%) (Electricity)	Positive	Alam et al. (2017)
	10. Head of household does not attained school (%) (Illiterates)	Positive	Nadeem et al. (2009)

(Continued)

Table 2. (Continued).

Component	Indicators	Functional relationship with vulnerability index	Source
Adaptive Capacity	1. HHs changes their cropping pattern (%) (Cropping pattern change)	Negative	Masud et al. (2017)
	2. HHs switch to non-farm activities (%) (Non-farm)	Negative	Masud et al. (2017)
	3. HHs live in the joint family (%) (Joint family)	Negative	Masud et al. (2017)
	4. HHs Kisan Call Centre (%) (KKC)	Negative	Masud et al. (2017)
	5. HHs started conservation of water bodies and soil to combat climate variability (%) (CWB)	Negative	Masud et al. (2017)
	6. HHs secure their crop through crop insurance (%) (Insurance)	Negative	Masud et al. (2017)
	7. HHs have storage capacity to procure agriculture products (%) (Storage)	Negative	Masud et al. (2017)
	8. HHs have taken professional training on climate change combating (%) Training)	Negative	Masud et al. (2017)
	9. HHs aware about nitrogen, phosphorus and potassium ratio (%) (NPK)	Negative	Masud et al. (2017)
	10. HHs have adjusting sowing dates (%) (ASD)	Negative	Masud et al. (2017)
	11. HHs growing more than one crop (multiple cropping) (%) (crop diversification)	Negative	World Bank (1997)

Note: HHs, households.
Source: Author’s estimate; Field survey, 2017.

A temperature surge by 3.6°C would reduce the crop growing period by 11 days (Abebe, Pathak, Singh, Bhatia, & Vinod, 2016).

Several studies have used farmers' perception of climate change as a proxy for an exposure index (Funk, Raghavan Sathyan, Winker, & Breuer, 2019; Masud et al., 2017; Shrestha, Chaweewan, & Arunyawat, 2017). Studies have revealed that > 90% of farmers have perceived that climate is changing in general, temperatures have sharply increased and rainfall patterns are nowadays less predictable in particular (Masud et al., 2017).

Although farmers are well aware of the adverse impacts of climate change on agriculture and livelihoods, the lack of availability of modern technology, small plot size and continuous droughts have reduced farmers' adaptive capacity (Shrestha et al., 2017). Therefore, the development of an exposure index to assess vulnerability is a prerequisite for social communities to cope up with climate change. In this study, exposure to climate change was assessed based on farmers' perception of climate change (Table 2).

Sensitivity is the degree to which the system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001) and the socioeconomic and ecological ability of a system to respond to climate change (IPCC, 2007). The population below the poverty line (BPL) is a section of the population that is deprived of resources and highly sensitive to climate change (Rai, Sharma, Sahoo, & Malhotra, 2008). Abid et al. (2015) found that a higher dependency on the household head, low diversification in agriculture and a lack of non-farm employment opportunities are key indicators influencing farmers' choices of adaptation measures. Further, Miranda, Hordijk, and Molina (2011) found that vulnerable households spend 3–5 h fetching drinking water from unsafe sources and also reported sharper conflicts over the use of water resources due to the water scarcity, depletion and poor access in the off-rainy season. Furthermore, illiterate households were at greater risk, indicating that education increases the capacity to cope with water-induced hazards (Nadeem, Elahi, Hadi, & Uddin, 2009). Also, the literature has shown that female-headed households are more vulnerable and less adaptive than male-headed households (Islam, Sallu, Hubacek, & Paavola, 2013; Nadeem et al., 2009; Opiyo, Wasonga, & Nyangito, 2014). The absence of a male household head increases livelihood vulnerability by limiting the household's ability to cope with extreme events as well as its access to livelihood assets and strategies (Islam et al., 2013). Further, Pariyar, Lovett, and Snell (2018) suggested that the access to, and control over, water for irrigation is one of the most important factors for increasing agricultural productivity, thereby affecting household food security and levels of poverty. With these pieces of evidence, the present study used socioeconomic and demographic data to develop a sensitivity index for different communities (Table 2).

Although the system might be significantly exposed or sensitive to climatic stress and shock, it cannot be said that it is vulnerable (Fellmann, 2012). A system's adaptive capacity influences vulnerability by adjusting both exposure and sensitivity (Gallopin, 2006). Successful and efficient adaptation is determined by three important factors: (1) timely perception and realization of changes in climate and the need to adopt measures to adapt; (2) incentives to adapt and the ability to adapt; and (3) need to alter the farming practices to maximize returns from new change climate (Fankhauser, Smith, & Richard, 1999; Sanghi & Mendelsohn, 2008; Bryan, Deressa, Gbetibouo, & Ringler, 2009). Masud et al. (2017) suggested that adaptation to climate change is a prerequisite to reduce its negative impact and harvest the benefits of adaptation. They further suggested that a higher degree of adaptation could be achieved through establishing training activities, skills development and capacity to strengthen the farmers' ability to adapt. Specialized training programmes are important not only for farmers but also for government officials who must provide appropriate technical support to farmers. Similarly, Ndambiri, Ritho, and Mbogoh (2013) suggested that adaptation strategies, such as crop diversification to reduce farmers' sensitivity to extreme events, drought, and erratic monsoons, provide ensured additional sources of income.

In order to capture the dynamics of climate change adaptation, farmers' perception of climate change was captured using questions such as do you perceive that the rainfall pattern is changing, and do you perceive that summer temperature is increasing. The results show that farmers are well-aware of climate change (Figure 4). Further, farmers who indicated an awareness of climate change were also asked about commonly used adaptation practices (Shrestha et al., 2017). Kawadia and Era (2017) find that a higher level of income and more farming experience significantly affect perceptions of the need for an increase in irrigation frequency. More importantly, farmer's decision to adapt or not to adapt is based on four sets of cognitive conditions: (1) perceived/predicted changes in climate and decisions to adjust to maximize their returns in the light of changing conditions; (2) perceived/predicted changes in climate that do not engender adaptation because of the constraints they face in adapting; (3) a failure to perceive/predict climate change yet adaptation occurs due to personal choices of on-farm changes or copying fellow farmers cropping patterns which they find interesting and profitable; and (4) a failure to perceive/predict climate change and to adapt. With these pieces of evidence, it is clear that adaptation capacity (inherent and planned) has a potential role in dealing with climate change. Therefore, this study developed an adaptive capacity index for different communities (Table 2).

Calculation of exposure, sensitivity and adaptive capacity indices and of a livelihood vulnerability index (LVI)

The main aim of this study was to integrate both biophysical and social vulnerability indicators in an LVI applicable at any scale and capable of identifying community vulnerability and the most vulnerable member groups of society. Vulnerability has a positive functional relationship with a system's exposure and sensitivity, and a negative relationship with a system's adaptive capacity (IPCC, 2007).

The indicators were normalized so as to use a single scale based on their functional relationship with vulnerability: equation (1) was used for a positive relationship with vulnerability and equation (2) was used for a negative relationship with vulnerability (Pandey & Jha, 2012):

$$Index_{sv} = \frac{S_v - S_{min}}{S_{max} - S_{min}} \tag{1}$$

$$Index_{sv} = \frac{S_{max} - S_v}{S_{max} - S_{min}} \tag{2}$$

where S_v is the raw value of the indicator at household level; and S_{min} and S_{max} are the minimum and maximum values of the indicator across all households (Hahn, Riederer, & Foster, 2009). In this way the indicators were normalized on a scale of 0 to 1.

The present study uses the normalized values of farmers' perception of climate change as proxy indicators to calculate an exposure index, normalized socioeconomic indicators to develop a sensitivity index, and normalized adaptation strategy indicators to develop an adaptive capacity index (Table 2) using equations (3–5) as follows:

$$Exposure\ index(EI) = \frac{R + S + D + W}{4} \tag{3}$$

$$Sensitivity\ index(SI) = \frac{F + DW + Ir + FHH + M + T + H + BPL + E + I}{10} \quad (4)$$

$$Adaptive\ Capacity\ index(EI) = \frac{CPR + NF + JF + KKC + CWB + In + St + Tr + NPK + ASD + CD}{11} \quad (5)$$

where the variables on the right-hand side are the normalized version of the indicators listed in Table 1.

Once the values for exposure, sensitivity and adaptive capacity for the community level had been calculated, the two contributing factors (exposure and sensitivity) were combined using equation (4) to obtain the community-level potential livelihood vulnerability index (Jamshidi, Asadi, Kalantari, Azadi, & Scheffran, 2019; Tripathi, 2017):

$$\mathrm{PLVI_d} = \mathrm{Exposure\ Index_d} - \mathrm{Sensitivity\ Index_d} \quad (6)$$

where $\mathrm{PLVI_d}$ is the potential livelihood vulnerability index score for the community *d*; Exposure $\mathrm{Index_d}$ is the calculated exposure score for the community *d*; and Sensitivity $\mathrm{Index_d}$ is the sensitivity score for the community *d*. Adaptive capacity, represented by A_d (equation 5), was also taken into consideration as follows:

$$\mathrm{LVI}_d = (\mathrm{Exposure\ Index}_d - \mathrm{Adaptive\ Capacity\ Index_d}) * \mathrm{Sensitivity\ Index_d} \quad (7)$$

PLVI and LVI were scaled so that –1 denotes the least vulnerable and 1 the most vulnerable.

The final step was the estimation of a regression model to examine the relationship between the livelihood vulnerability index, LVI, and a set of explanatory variables reflecting the way climate change may affect it. The cross-section of 200 households in Jhansi and Jalaun districts was used. The livelihood vulnerability of *i*th household was specified as:

$$LVI_i = a_i + \sum \beta_{ji} X_{ji} + \varepsilon_i, i = 1, 2, \ldots .200; j = 1, 2 \ldots .25 \quad (8)$$

where X denotes a set of explanatory variables; j denotes the jth explanatory variable; and ε_i is an error term.

RESULTS AND DISCUSSION

Socioeconomic characteristics of the sample households

The socioeconomic characteristics of sample households of study area are indicative of the economic challenges confronted in these areas compared with UP and India as a whole (Tables 1 and 3). The average landholding and income of sample households were lower than on average in UP and India (1.18 ha). Other personal attributes of sample households, namely low literacy rate and a higher proportion of female-headed households, again reflects the backwardness in the region. The share of sample households with access to basic amenities consisting of an electricity connection, sanitation and drinking water facilities was far lower than on average in UP and India (Tables 1 and 3). Moreover, the majority of the sample households were young, with a mean age of 31.36 and 30.04 years in Jalaun and Jhansi districts, respectively. Besides, between 26% and 29% of the population lay below the poverty line. In totality, the study results show that the majority of the sample households lacked basic amenities, and were likely to be strongly impacted by climate change events.

Table 3. Socioeconomic characteristics of sample households

Characteristics	Jalaun	Jhansi
Female-headed households (%)	44.74	44.18
Literacy rate of households (%)	49.76	50.24
Unemployment rate in households (%)	50.06	49.94
Mean income of households (US$)	332.07	372.24
Average land size of households (in acre)	0.26	0.35
Average age of household (years)	31.36	30.04
Marital status (% of married to total family members)	52.39	53.32
Households having electricity connection (%)	65.00	80.00
Households having sanitation facility (%)	57.00	51.00
Households using improved drinking water facility (%)	61.00	60.00
Households below poverty line (%)	29.00	26.00

Note: US$1 = 69.49 Indian rupees (INR).
Source: Field survey data, 2017.

Farmers' perceptions of climate change

The majority of sample farmers had perceived a higher degree of variability in climate parameters. More than 90% of farmers perceived that summer days had become hotter, the frequency of droughts had increased and the water level declined (Figure 4). Further, > 60% of farmers opined that rainfall has declined. As well as quantitative indicators, qualitative evidence was collected to capture farmers' experiences of climate change. For instance, farmers reported that droughts had a dual impact on livelihoods. First, most of the farm families in survey villages had lost crops or cattle or both. As the villagers themselves struggled to live during crisis times, the survival of cattle was the last thing on their minds. As matters stood, the number of livestock owned by farmers in Amra village of Jhansi district had declined to 1500 compared with 8000 just four years earlier (i.e., in 2012–13). Moreover, there is no provision of compensation in the event of the death of cattle. In a sense, livestock has not been considered a resource in the state policy of UP. Farmers perceived that the government had not made any visible and significant provisions for livestock survival during conditions of extreme climatic variability, dissuading them from rearing livestock as an enterprise.

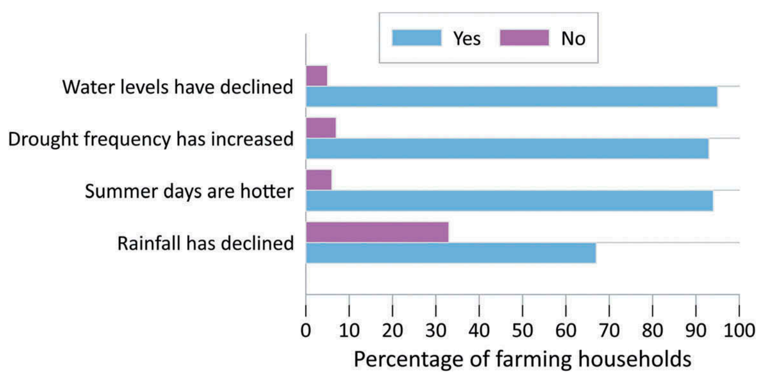

Figure 4. Farmers' perception of climate change.

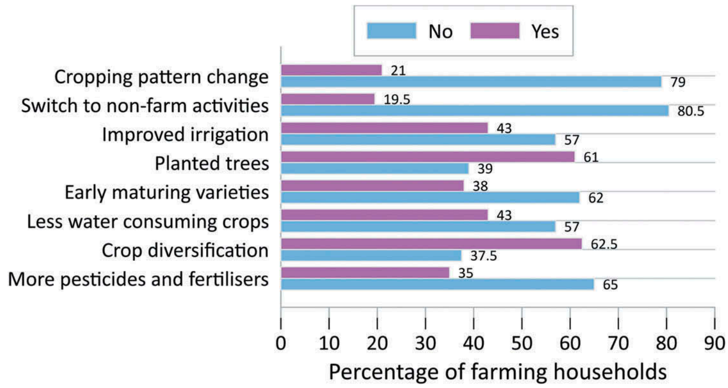

Figure 5. Adaptation strategies adopted by the surveyed households.

In Jalaun and Jhansi districts, erratic climatic conditions and a shortage of rainfall inhibit improvements in agriculture, livestock rearing and other livelihood systems in the region. At the same time deforestation and frequent droughts in the last five years have substantially reduced the overall capacity of the region to harvest and store rainwater.

Adaptation strategies in rainfed agriculture

The sample households of the region adopted differential adaptation strategies to cope with changing climate. More than 60% of households planted eucalyptus, citrus and mango trees surrounding the farmlands and diversified their cropping pattern towards less water consuming crops (Figure 5). Since Bundelkhand is a dry region, irrigation has a potential impact on farm revenue. The study has observed that > 40% of sample farmers had increased their irrigation coverage by digging ponds, storing surface rainwater and grow less water requiring drought-resistant varieties of jowar (Pusa Chari-615), bajra (APFB-2), kharif pulses (PUSA Arhar-16) and oilseeds (RCC-4). Few farm households believe that by increasing inputs, productivity could be increased. By assuming this, nearly 35% of households have increased the use of bio-pesticides and fertilizers. Besides, 20% of farm households were engaged in non-farm activities. The negligible numbers of sample households were engaged in non-farm employment opportunities during the off-rainy season and higher dependence on agriculture restricted farmers to change the cropping pattern and switch to non-farm employment activities.

Exposure index (EI)

A characteristic of the present study is the linking of biophysical and social vulnerability between and within communities. Biophysical factors such as a rise in temperature, variability in rainfall and a declining water table interact with structural inequalities such as socio-economic and political marginalization, a high level of poverty, a lack of livelihood opportunities, caste and gender-based hierarchies between social groups. In this context, Raghav and Katsushi (2004) argued that the interaction of these factors exposes even relatively affluent households (General community, educated and large land holders) to persistent climate shocks. Indeed these groups are often hit harder than poorer households because the latter mitigate risks through diversification. This study noted a similar result in that farmers belonging to the Scheduled Tribes (ST) community, with an exposure index score 0.908 of Jalaun district (Table 4), are more exposed to climate shocks than other communities.

Comparing farmers' perception between General and ST communities reveals that about 76% of farmers belonging to the General community perceived that rainfall has declined,

Table 4. District and social group exposure indices

Indicators	Jalaun district					Jhansi district				
	General	OBC	SC	ST	All classes	General	OBC	SC	ST	All classes
Rainfall	0.760	0.770	0.870	0.910	0.828	0.870	0.850	0.880	0.890	0.873
Summer	0.790	0.790	0.790	0.890	0.815	0.680	0.870	0.950	0.760	0.815
Drought	0.830	0.900	0.810	0.950	0.873	0.870	0.890	0.970	0.690	0.855
Water level	0.830	0.780	0.880	0.880	0.843	0.780	0.910	0.880	0.950	0.880
Exposure index	0.803	0.810	0.838	0.908	0.840	0.800	0.880	0.920	0.823	0.856

Note: General, OBC, SC and ST indicate the exposure of farmers belonging to the General, Other Backward Castes, Scheduled Caste and Scheduled Tribes, respectively.
Source: Field survey data, 2017.

while about 91% of farmers belonging to the ST community perceived. Nearly 79% of farmers belonging to the General community perceived that summer day becoming hotter, while about 89% of farmers belonging to the ST community perceived. About 83% of farmers belonging to the General community have perceived that drought is now a common phenomenon, while 95% of farmers belonging to the ST community have perceived. Similarly, about 83% of farmers belonging to the General community have perceived that water level has substantially declined over the past five years, while about 88% of farmers belonging to the ST community perceived. In totality, exposure indices that reflect farmers' perception (biophysical vulnerability) showed that about 84% of farmers belonging to General, OBC and SC communities perceived that summers have become hotter, and the frequencies of drought have increased, while > 90% of farmers belonging to ST community perceived.

Sensitivity index (SI)

A higher incidence of poverty, wide variability in access to basic amenities and a high dependence of livelihoods on natural resources are some of the primary determinants of sensitivity to climate change (Table 5). A relative lack of clean energy for cooking, treated drinking water, medical facilities, and sanitation and housing facilities made farmers belonging to STs in the Jalaun district more sensitive to climate change than those in the Jhansi district.

The cross-sectional index and community analysis revealed the extent and dimensions of social vulnerability. A comparison of the index scores of the General and ST communities revealed that about 39% of farmers belonging to the General community cooked food with renewable resources compared with only 9% of farmers belonging to the ST community. About 57% of farmers belonging to the General community had access to pure and safe drinking water compared with only about 9% of farmers belonging to the ST community. Similarly, about 73% of farmers belonging to the General community had 24*7 access to water for irrigation compared with only about 27% of farmers belonging to the ST community. About 70% of farmers belonging to the ST community are not in a position to avail themselves of private medical facilities due to low awareness and high cost. Access to sanitation and electricity and the nature of houses which are vital components of livelihood security were associated with large differences between farmers belonging to the General and ST communities. Furthermore, about 59% of farmers belonging to the General community

Table 5. District and social group sensitivity indices

Indicators	Jalaun district					Jhansi district				
	General	OBC	SC	ST	All classes	General	OBC	SC	ST	All classes
Cooking source	0.618	0.760	0.800	0.910	0.772	0.560	0.630	0.710	0.760	0.665
Hand pump	0.439	0.560	0.770	0.920	0.672	0.350	0.470	0.850	0.760	0.608
Irrigation	0.325	0.470	0.560	0.890	0.561	0.260	0.360	0.430	0.730	0.445
Female headed	0.405	0.620	0.740	0.830	0.649	0.380	0.540	0.610	0.630	0.540
Free medical facility	0.274	0.390	0.560	0.730	0.489	0.220	0.260	0.430	0.690	0.400
Sanitation facility	0.670	0.780	0.850	0.900	0.800	0.590	0.630	0.750	0.720	0.673
Nature of house	0.570	0.660	0.780	0.950	0.740	0.490	0.560	0.530	0.810	0.598
Below poverty line	0.590	0.750	0.870	0.920	0.783	0.450	0.620	0.750	0.730	0.638
Electricity access	0.770	0.810	0.890	0.930	0.850	0.540	0.650	0.680	0.690	0.640
Education level	0.800	0.860	0.920	0.960	0.885	0.620	0.710	0.740	0.650	0.680
Sensitivity index	0.546	0.666	0.774	0.894	0.720	0.446	0.543	0.648	0.717	0.589

Note: General, OBC, SC and ST indicate sensitivity status of farmers belonging to the General, Other Backward Castes, Scheduled Caste and Scheduled Tribes, respectively.
Source: Field survey data, 2017.

were living under the poverty line compared with about 92% of farmers belonging to the ST community.

In this region vulnerability is multidimensional, with composite sensitivity indices revealing that farmers belonging to the ST community were characterized by a relatively higher degree of sensitivity than other communities.

Adaptive capacity index (ACI)

Farmers undertook a range of climate risk management strategies including cropping pattern change, a switch to non-farm activities, insuring crops, adjusting sowing dates, diversifying cropping patterns, strengthening storage capacity, equipping themselves with modern agricultural training from experts and conserving water resources (Table 6). Strategies were typically undertaken independently but were often buttressed by government-sponsored assistance as in the case of fertilizer and water subsidies. The Horticulture Department helped farmers adopt drip irrigation, and a convergence of drought-proofing activities with employment schemes was associated with the subsidized digging of farm ponds. However, these schemes were typically profitable for the large farmers belonging to the General community because they involved economies of scale (Singh, Bhawna, Surendra, & Arshad, 2019).

Table 6. District and social group adaptive capacity indices

Indicators	Jalaun district					Jhansi district				
	General	OBC	SC	ST	All classes	General	OBC	SC	ST	All classes
Cropping pattern	0.120	0.100	0.060	0.020	0.075	0.510	0.467	0.290	0.100	0.342
Switch to non-farm	0.260	0.230	0.120	0.100	0.178	0.620	0.320	0.310	0.150	0.350
Joint family	0.310	0.240	0.100	0.060	0.178	0.320	0.230	0.336	0.249	0.284
IT	0.250	0.120	0.110	0.044	0.131	0.330	0.300	0.367	0.167	0.291
Water	0.260	0.190	0.120	0.090	0.165	0.320	0.269	0.322	0.213	0.281
Crop insurance	0.310	0.200	0.190	0.090	0.198	0.410	0.210	0.210	0.250	0.270
Storage capacity	0.308	0.260	0.230	0.130	0.232	0.270	0.355	0.326	0.350	0.325
Training	0.372	0.299	0.240	0.208	0.280	0.210	0.310	0.215	0.208	0.236
Use of fertilizers	0.300	0.150	0.120	0.080	0.163	0.276	0.316	0.223	0.185	0.250
Sowing dates	0.330	0.301	0.210	0.120	0.240	0.260	0.259	0.339	0.197	0.264
Multiple cropping	0.320	0.260	0.180	0.083	0.211	0.320	0.304	0.302	0.200	0.282
Adaptive capacity index	0.285	0.214	0.153	0.093	0.186	0.350	0.304	0.295	0.206	0.289

Note: General, OBC, SC and ST indicate adaptive capacity status of farmers belonging to the General, Other Backward Castes, Scheduled Caste and Scheduled Tribes, respectively.
Source: Field survey data, 2017.

Across the communities, the risk management strategies of farmers differed in accordance with their assets (landholding, water availability, etc.), networks (with labour contractors in nearby towns, with other communities) and personal factors (such as education level, gender and risk aversion). More precisely, large farmers were more involved in cropping pattern change than marginal and small farmers.

Cross-sectional indices revealed the extent and dimensions of the adaptive capacity of mainstream social communities. About 26% of farmers belonging to the General community had diversified their occupational profile (switching to non-farm work) compared with only 10% of all farmers. Nearly 30% of farmers belonging to the General community are living in the joint family, while only 6% of farmers belonging to the ST community are living in the joint family. Through social and economic bonding farmers belonging to the General community are highly capable (adaptive capacity) to deal with adverse impacts of climate change. About 25% of farmers belonging to the General community have taken expert advice from the agricultural professionals (access of information technology), while about only 4% of farmers belonging to the ST community have benefitted.

Further, ex-ante coping measures provide insured agricultural returns. About 31% of farmers belonging to the General have insurance cover, while only 9% of farmers belonging to the ST community have insurance cover. Ex-post coping strategies are also equally important to deal with climate change, such as storage capacity. Nearly 30% of farmers belonging to the General community have storage capacity for farm produce, while only 13% of farmers belonging to the ST community have storage capacity. Furthermore, about 33% of farmers belonging to the General community have changed their sowing data

Table 7. Social group livelihood vulnerability indices

Indicators	Jalaun district					Jhansi district				
	General	OBC	SC	ST	All classes	General	OBC	SC	ST	All classes
EI	0.803	0.838	0.810	0.908	0.840	0.800	0.920	0.880	0.823	0.856
SI	0.546	0.666	0.774	0.894	0.720	0.446	0.543	0.648	0.717	0.589
ACI	0.320	0.260	0.180	0.083	0.211	0.320	0.304	0.302	0.200	0.282
PLVI	1.454	1.504	1.584	1.697	1.560	1.269	1.463	1.528	1.517	1.444
LVI	0.321	0.385	0.488	0.644	0.453	0.224	0.334	0.375	0.430	0.338

Note: EI, SI, ACI, PLVI and LVI are the exposure index, sensitivity index, adaptive capacity index, potential livelihood vulnerability index and livelihood vulnerability index, respectively.
Source: Field survey data, 2017.

(adaptation strategy), while 12% of farmers belonging to the ST community have adjusted sowing dates. Multi-copping also has well-recognized climate adaptation strategy. About 32% of farmers belonging to the General community have diversified their cropping pattern, while only 8% of farmers belonging to ST community have diversified their cropping pattern. In totality, farmers belonging to the ST community have relatively lower adaptive capacity than farmers belonging to the General, OBC and SC communities in Jalaun district over Jhansi district.

Livelihood vulnerability index (LVI)

The relative strength and interaction of exposure, sensitivity and adaptive capacity indices determine vulnerability. Exposure indices for farmers belonging to the ST community in Jalaun and Jhansi districts indicate that they are more highly exposed to climate change than other communities. Sensitivity indices for farmers belonging to the ST community were also relatively high, whereas these groups had a lower adaptive capacity (Table 7). Differences between the potential and actual livelihood vulnerability indices (PLVIs and LVIs) reflect the potential role of adaptive capacity in coping with climate change.

The findings of this study have revealed that adaptive capacity plays a decisive role in determining climate vulnerability for the sampled farmers. Both the ex-ante (insurance) and ex-post (storage capacity) adaptation had a positive impact on the probability of a stable livelihood strategy. However, adaptive capacity is mainly a characteristic of the General community and farmers with large holdings. For instance, access to financial services and workforce availability has enabled farmers to deal with climate adaptation barriers. Farmers who belong to an economically challenged community (ST) are more likely to be engaged in precarious urban and agro-industrial work, confirming that people with higher caste status (General community) are better endowed with the resources required for participation in non-farm work. In this way, the relative vulnerability of farmers belonging to the ST community is reinforced.

To explain variations in livelihood vulnerability, the LVI index was, as already mentioned, regressed on several explanatory variables. The results are reported in Table 8. Variance inflation factors were relatively low indicating that multicollinearity was not a significant problem. An adjusted R^2 of 0.55 indicated that 55% variation in the LVI was explained by the model.

Table 8. Regression of the livelihood vulnerability index (LVI) on the explanatory variable

Dependent variable: LVI	Coefficients	*t*-statistics	*p*-value
Rainfall	12.452	2.45	0.01
Summer days	0.124	1.43	0.02
Drought	0.005	3.42	0.01
Water level	0.050	1.42	0.05
Forest	0.021	3.21	0.09
Drinking water	0.045	1.29	0.02
Irrigation	0.006	2.09	0.04
FHH	0.007	3.18	0.01
Medical	−0.007	−3.18	0.00
Toilet	0.034	2.29	0.00
House	0.005	1.82	0.01
BPL	0.014	2.42	0.05
Electricity	0.042	1.59	0.06
Illiterates	0.650	1.85	0.07
Cropping pattern change	−0.003	−1.34	0.02
Non-farm income	−0.005	−1.31	0.08
Joint family	−0.004	−2.19	0.07
KKC	−0.008	−3.24	0.01
CWB	−0.045	−1.16	0.06
Insurance	−0.006	−2.09	0.04
Storage	−0.003	−2.29	0.02
Training	−0.005	−1.31	0.26
NPK	−0.007	−2.09	0.05
ASD	−0.013	−1.31	0.00
Crop diversification	−0.191	−2.19	0.02
Model summary			
R^2		0.62	
Adjusted R^2		0.55	
F-statistic		9.15	
p-value		0.000	
Observations		200	

Source: Field survey data, 2017.

The results show that the coefficients of rainfall, summer days, drought, water level, forest, drinking water, irrigation, toilet facilities, house, poverty, electricity and illiteracy were all positive and statistically significant, while medical services, cropping pattern change, non-farm income, joint family, Kisan Call Centre (KKC), conservation of water bodies and soil (CWB), insurance, storage, training, nitrogen, phosphorus and potassium ratio, adjusting sowing dates (ASD) and crop diversification were all negative and statistically significant. In other words, the majority of the variables related to exposure and sensitivity had a significant effect on farmers' livelihood vulnerability. The exception was access to medical services (Table 8). The value of the intercept was, however, high indicating the possible role of other variables not included in the estimated model.

CONCLUSIONS AND POLICY RECOMMENDATIONS

This study of the nature and extent of livelihood vulnerability in the Bundelkhand region of UP involved the calculation of indices to examine the role of biophysical and social factors in determining the vulnerability of mainstream social communities of India. It showed that while biophysical factors are increasing exposure of climate change, social factors restrict farmers' ability to cope with it.

This study revealed that the majority of sampled farmers perceived climate change as a factor adversely affecting farming and their livelihoods. Three main factors explain the high degree of vulnerability in the most economically challenged community, that is, ST. First, these farmers were highly exposed with the least adaptive capacity to drought. Second, they had the least access to basic amenities increasing their sensitivity to climate change. Lastly, the degree of vulnerability varies from district to district and household to household. The results suggest that households that are less sensitive and less exposed to climate risks are unlikely to invest in climate risk management strategies, and vice versa. More specifically, the study revealed that sample households belonging to ST communities are highly exposed to climate change with a higher degree of biophysical vulnerability. Farmers have adopted several climate risk management strategies to overcome biophysical vulnerability. However, social vulnerability (i.e., lack of access to basic amenities) was the main constraint on coping with climate change.

The main question that arises in these circumstances is whether vulnerable households should remain in the agricultural sector or migrate. Migration is, however, not always a good coping strategy. A lack of technical and formal education remains a major barrier for farmers seeking to diversify their livelihoods by moving to the service and industrial sectors. In these circumstances migration is associated with a high probability of a greater vulnerability and a livelihood crisis due to the existence of an even smaller adaptive capacity. If, however, they remain in agriculture and find sustainable solutions to climate change such as conserving water bodies so that water is available for agriculture and livestock in the dry season, they will become more resilient in the face of drought. The study suggests that farmers have largely opted for this option. Nearly 40% of farmers have enhanced their resilience by adopting local solutions drawing on institutional credit and insurance support.

The study has several policy implications. First, since the water table is declining continuously and creating a water crisis even in the rainy season for agriculture and domestic consumption, community participation in the conservation of water-bodies is vital. Second, lower farm yield is a major barrier in sustainable development and secure livelihoods where agriculture is solely a source of income. In these areas, the adoption of crop varieties that require less water, are drought tolerant and mature early will help increase farm productivity and reduce cultivation costs. Third, the majority of households rely on forest resources for cooking. The use of wood as fuel leads to chronic diseases, which require additional expenditure. The application of solar energy for cooking can be a better option. Nowadays, solar energy is being utilized extensively not only for cooking but also for lighting and other purposes. Fourth, open defaecation is still a reality among the surveyed households, despite the construction of toilets in a mission mode by the Government. If community toilets were constructed in a community participation framework, water and time could be saved and protection from disease and health hazards increased.

Apart from aforesaid micro adaptation strategies, the study also suggests there is a need for macro-level planning to deal with climate change. First, advanced regional weather forecasting systems capable of providing farmers with accurate information that will enable them to change cropping patterns and adjust farming practices are required. Second, it is vital that public and private resources are mobilized to deal with regional disparities and strengthen inter and intra-community relationships. In that way, farmers will be well-equipped biophysically and socially to deal with disasters that occur in the future.

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DEVELOPMENT OF SUSTAINABLE LIVELIHOOD SECURITY INDEX FOR DIFFERENT AGRO-CLIMATIC ZONES OF UTTAR PRADESH, INDIA

Surendra Singh and Sanatan Nayak***

ABSTRACT

The present study has attempted to examine the livelihood status of nine agro-climatic zones (ACZs) in the State of Uttar Pradesh in India. The United National Development Programme's (UNDP) methodology has adopted to develop a practical, innovative and ready-to-use sustainable livelihood security index (SLSI) for different ACZs. A total of 84 rational indicators were employed that covered seven dimensions of livelihood security, i.e. infrastructure security, agricultural sustainability, economic security, social security, food security, environmental security, and health security. The quintile estimation was also employed to identify low productive districts with reference to Uttar Pradesh. The performance of ACZs in terms of estimated indices for different dimensions of SLSI has also compared and ranked across developmental indicators. Study findings revealed that Bundelkhand zone has the lowest livelihood security than that of other ACZs. Least access of basic amenities, least social and health security, and higher reliance on agriculture for livelihoods were the main influencing indicators responsible for lower livelihood security in Bundelkhand zone. At the same time, better infrastructural and health facilities and least reliance on agriculture for livelihoods were main contributing indicators for the highest livelihood security in Vindhyan Zone. The present study's findings also matched with the results of studies conducted by the Planning Commission and NITI Aayog. The policy insights from the analysis suggest the need for prioritising vulnerable and less developed ACZs to arrest regional imbalances, prevent overexploitation and to leverage the unutilised potential of the districts.

Keywords: Sustainable Livelihood Security Index, Agro-Climatic Zones, Regional Disparities.

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Introduction

Growing pressure on natural resources, burgeoning population, change in consumption pattern and climate variation accentuate the challenges for normal functioning of ecosystem services and livelihood sustainability (Gerst et al., 2014; O'Neill et al., 2018). Variations in the society's productive base are embedded as an intricate interplay of a multitude of factors like natural resource endowments, environmental conditions, infrastructure development, demographic features and institutional building (Dasgupta, 2007). Differences across these developmental factors determine the household's resiliency and vulnerability shocks (Singh and Hirenath, 2010). Though the Indian planning process has made concerted efforts in addressing various social and economic barriers, still regional disparity continues to persist as a barrier in the development path (Chaudhry, 2018; Singh, 2020). Livelihoods security is one of the ultimate determinants of the nation's well-being and overall development (Chamber and Conway, 1992; Scoones, 1998). India has reached very close to a situation, where renewability of the most natural resources has ceased to the magnitude of overexploitation (Chakraborty et al., 2009). The ever-increasing anthropogenic dependence of the booming population on the ecosystem has outpaced the resilience of natural resources. There is now ample evidence to establish that poverty reduction and economic growth can only be sustained if natural resources are managed on a sustainable basis (Islam et al., 2015; Singh and Alka, 2019). A significant portion of India's population, particularly the rural poor, depends on natural resources, including land and forest for subsistence (GoI, 2006). The livelihood crisis among rural poor in India has basically been fuelled by the incessant decline in productivity of agriculture due to the failure of natural resource resilience.

The ecstasy of technocratic quests for development excellence has grossly built the resilience of natural resources, including land and forests. Agrarian statistics revealed that in the last 15 years (2001-2015), just a 0.2 per cent increase in agricultural land of the country was recorded, which is quite insufficient to support the population boom of the country unless and until the waste and fallow lands are put to some productive purpose. Land degradation is an anthropogenic process and poses the biggest threat to the livelihood security of rural communities across the world. The rapid decline in per capita availability of land due to inheritances during successive generations, besides unrestrained land acquisitions or diversions for various non-agrarian purposes of the fast-growing urbanisation, forms a major bottleneck for farming returns. All of these factors combined with an increased rate of land degradation contribute to livelihood crisis, which can only be resolved by optimisation of land productivity through multiple land use.

The livelihood is sustainable when it can offset risks, withstand and recover from shocks and enhance capabilities and assets, without undermining the natural resource base (Chamber and Conway, 1992; Scoones, 1998). A significant aspect of sustainable livelihood scheme relates to the systematic understanding and determining of barriers arising from the socio-economic, political and the institutional arena that deprives people of several resources and restricts their capability (Sathyan et al., 2018).

More specifically, two main research questions are being widely discussed in the research academia. First, what are the key drivers that responsible for lower livelihoods security? Second, what are the sustainable solutions? Therefore, the present study has three key objectives. First, develop a practical, innovative and ready-to-use sustainable livelihood security index for nine agro-climatic zones (ACZs) in Uttar Pradesh. Second, examine the extent and dimension of the livelihood security between and within ACZs. Last, check the reliability and practicability by comparing sustainable livelihood security index (SLSI) to previous studies, viz. Planning Commission (2001) and NITI Aayog (2018).

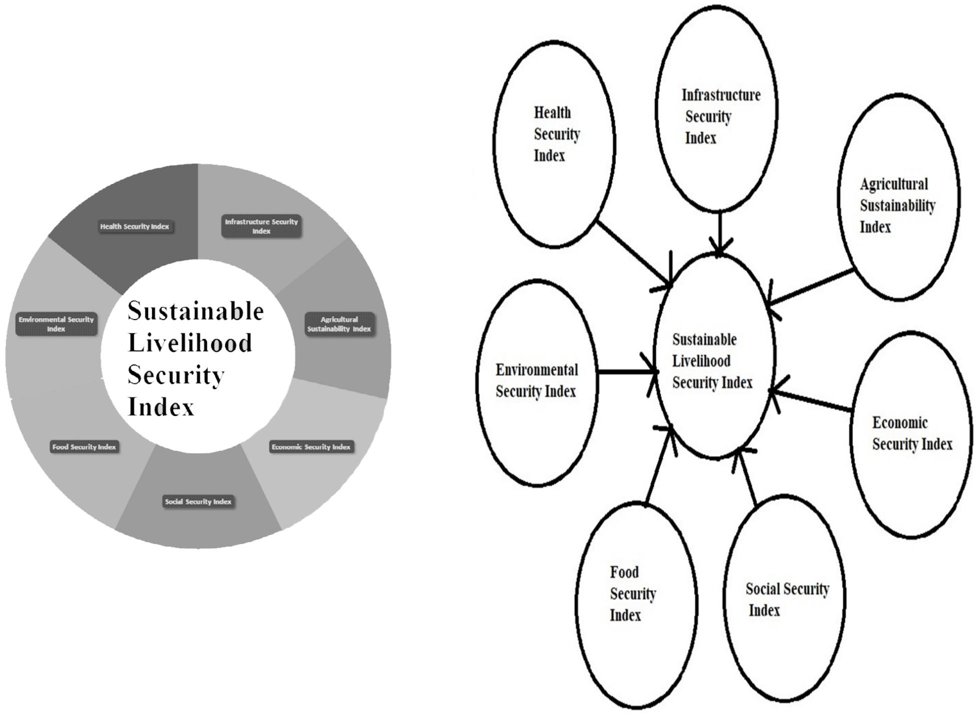
Methodological Framework

Development of Sustainable Livelihood Security Index: Analytical Framework

The sustainable livelihood security (SLS) is a function of multiple factors, viz. infrastructure security, agricultural sustainability, economic security, social security, food security, environmental security, and health security (Rai et al., 2008; UNEP, 2011; Shyamalie and Saini, 2010; Marco and Yuan, 2012;). Singh and Hiremath (2010) suggested that a practical SLS has a wider generic meaning, encompassing current concerns and policy requirements pertaining to sustainable development. The practicality of SLS has both macro and micro-levels. The macro-level implications for ensuring SLS include stabilising population, reducing distress migration, preventing exploitation, and supporting long-term sustainable resource management (Singh and Hiremath, 2010). On the other hand, at the micro (regional) levels, the critical ingredients of SLS are 'adequate stocks and flows of food and cash to meet basic needs' and access to resources, income, and assets to offset shocks' (McCraken and Pretty, 1988). The integrated and ultramodern SLS can manage rural-urban distress migration by reducing regional imbalances of economic development, resource degradation and social exploitation through equitable distribution of assets, ownership of private and common-pool resources under the ecological security agenda. Meanwhile, SLS aims to provide the means for meeting the basic needs of humans; it is more sustainable as a policy tool than as a strategy aimed at the mere provision of basic needs. It has the sole progressive agenda to meet the present population's demand without compromising the demand for future generation (Chambers, 1986).

The utility and replicability of a given index or measure depend primarily on its simplicity and flexibility, not on its complexity and rigidity (Singh and Hiremath, 2010). To operationalise the concept of SLS within the context of sustainable development (SD), Saleth and Swaminathan (1993) propounded the following propositions: (i) since SD is contextual, what is sustainable in a given region or ecosystem need not necessarily be sustainable in another region or ecosystem; hence, there cannot be a unique recipe for achieving SLS everywhere; and (ii) SD is a hierarchical and interrelated process, as the sustainability requirements of households, resources, ecosystems, regions, nations, and ultimately, the planet itself are critically interlinked.

The present study has developed one practical, innovative and ready-to-use sustainable livelihood security index (SLSI) for different agro-climatic zones (ACZs) in the State of Uttar Pradesh in India. SLSI was developed in three steps. Firstly, rational and region-specific indicators were selected in a broader sense of SLSI. Secondly, weights were assigned for each indicator and multiplied into the relative index for each indicator. Thirdly, indicators were sub-grouped into seven sub-components (Figure 1) to develop the sub-indices. Finally, sub-indices were aggregated to develop the final SLSI. The SLSI has seven sub-components (indices) covering infrastructure security, agricultural sustainability, economic security, social security, food security, environmental security and health security.



Source: Author’s Calculation, 2020.

Figure 1: Framework for Sustainable Livelihood Security

Study Area

Uttar Pradesh is the most populous State in the country, accounting for 16.4 per cent of the country's population (Census, 2011). It is also the fourth largest State in geographical area covering 6.88 per cent of the country's geographical area, encompassing 2,43,290 square kilometres and comprising 75 districts, 901 development blocks and 200 million inhabited villages. The population density of the State is 829 people per square kilometres as against 382 in the country. The total population of the State was 88 million in 1971. It increased to 199 million in 2011. More than 70 per cent of the population is employed in agriculture. This shows the continued pressure of the working population in the agriculture sector.

The distinguishing feature of Uttar Pradesh's economy is its regional imbalances. In terms of economic indicators, i.e. agricultural productivity, infrastructure facilities and industrial growth, the Uttar Pradesh's economy can be categorised into nine zones: Bhabhar and Terai, Bundelkhand, Central, Eastern plain, Mid-western plain, North- eastern plain, South-western semi-arid, Vindhyan and Western plain. The Western plain zone is agriculturally prosperous. It is relatively industrialised and has seen a greater degree of urbanisation. On the other hand, the Bundelkhand zone has low agricultural growth and less number of industrial units. The lesser gross value of industrial products marks out this region as the least developed in the State.

In terms of almost all demographic, social and economic indicators like medical facilities, the teacher-student ratio in primary schools, birth rate, death rate, infant mortality rate, literacy, per capita income, electrification of villages, per capita power consumption, etc., Uttar Pradesh is often seen as a case study of development in a region of India that currently lags behind other parts of the country (Census, 2011).

Life in Uttar Pradesh is short and uncertain. Here, females expect to live less than 55 years and the under-five mortality rate is as high as 141 per thousands (NFHS, 2015-16). Similarly, the problems of the education system are exacting. Due to public apathy, the schools are in disarray; the privately run school are functional but beyond the reach of ordinary people.

The climate is sub-humid continental. Maximum temperature varies between 26-41^{0}C while minimum temperature varies between 7-23^{0}C, and mean rainfall between 75- 150 cm. Major crops, viz. rice, sugarcane, millets, gram, barley, oilseeds, pulses and cotton are produced.

Data Sources

The present study uses secondary data published by different organisations of the Government of India, viz. Census 2011, NSO 69th (July-December, 2012) and 70th round (January-December, 2013), National Family Health Survey (2015-16), Department of Agriculture and Statistics, Uttar Pradesh and the Indian Meteorological Department during 2011-16.

Table 1: Indicators and Sub-components, Weight Assigned for Indicators and Sub-components for Sustainable Livelihood Security Index

Sub-components	Indicators	Direction	Indicator Weight (%)	Sub-Component weight (%)
Infrastructure Security	% of population having Kutcha House	↓	2	20
	% of population having Semi-Pucca House	↑	5	
	% of population having Pucca House	↑	5	
	% of population having access to Education Institutions	↑	5	
	% of population having access to medical services	↑	5	
	% of population having access to Post office	↑	5	
	% of population having access to Telephone	↑	5	
	% of population having access to Transportation services	↑	5	
	% of population having access to banking services	↑	5	
	% of population having membership of Agri Credit society.	↑	5	
	% of population having access to All Seasonal Roads	↑	5	
	% of population having access to Power Supply	↑	5	
	% of population having access to Drainage System	↑	5	
	Population Density (per 1000 per KM)	↑	5	
	No. of Regulated Markets	↑	5	
	No. of Veterinary Institute	↑	3	
	% of population having access to Garbage Collection	↑	5	
	% of population having Sanitation facility	↑	5	
	% of population using clean energy for Cooking	↑	5	
	% of population having access to Safe Drinking Water	↑	5	
	% of population living in Slums	↓	5	
Agricultural Sustainability	% of agricultural labours to total population	↑	20	10
	% of cultivators to total population	↑	10	
	Storage capacity (MT)	↑	10	
	No. of tractors and power operated implements	↑	10	
	% of livestock	↑	5	
	% of rainfed area to total geographical area	↓	5	
	% of area under watershed	↑	10	
	irrigation intensity	↑	10	
	% of area under surface irrigation	↑	5	

	% of un-irrigated area	↓	5	
	% of marginal farmers	↓	5	
	% of area under marginal farmers	↓	5	
Economic Security	% of income from agriculture, forestry, fishing	↑	10	20
	% of income from crops	↑	10	
	% of income from livestock	↑	10	
	% of income from forestry and logging	↑	10	
	% of income from fishing and aquaculture	↑	10	
	% of income from mining and quarrying	↑	10	
	Per Capita Income	↑	5	
	Annual Per Capita Expenditure	↑	5	
Social Security	% of Household industry workers	↓	10	10
	% of Non-workers	↑	15	
	% of Female-Headed HHs	↓	15	
	Sex Ratio	↓	10	
	% of Scheduled Caste Population	↓	10	
	% of Scheduled Tribe Population	↑	20	
	% of Out-Migration Rate	↑	10	
	% of Pop. having Health Insurance	↓	10	
Food Security	Per Capita Availability of Milk (in litre)	↑	15	10
	Pulses Productivity (Ton/Hac.)	↑	15	
	Oilseeds Productivity (Ton/Hac.)	↑	15	
	Cereals Productivity (Ton/Hac.)	↑	20	
	Cropping Intensity	↑	20	
	Fish Production (in Kg)	↑	15	
Environmental Sustainability	Air Quality Index (in PM10)	↓	5	20
	% of Ground Water with Nitrate	↓	5	
	No. of Deep Tube wells	↓	5	
	Water Level (in Meters)	↓	5	
	% of forest area forest degraded	↑	5	
	% of area Gullied and/ or ravenous land	↑	5	
	% of area with Dense Scrub	↑	5	
	% of area with Open Scrub	↑	3	
	% of area with Waterlogged	↓	5	

	% of area affected by salinity/alkalinity	↓	5	
	% of area under Waste/ Degraded Land	↓	5	
	% of Area not available for cultivation	↓	5	
	% of area under Ground Irrigation	↓	2	
	Maximum Temperature (in 0C)	↓	10	
	Minimum Temperature (in 0C)	↓	10	
	Rainfall (in M.M)	↑	10	
	% of Forest Area	↑	10	
Health Security	% of population taking Iodised Salt	↑	10	10
	% of Women (BMI) is below normal	↓	20	
	% of Men (BMI) is below normal	↓	20	
	% of Overweight Women	↓	30	
	% of Overweight Men	↓	10	
	No. of Infant Deaths per 1000 births	↓	10	
	Literacy Rate (in %)	↑	5	
	% of population having employment through MGNREGA	↑	10	
	% of below poverty line (BPL) population	↓	5	
	% of HH taken formal training in agriculture	↑	10	

Source: Author Calculations, 2019. Note Direction ↓ indicates the negative relationship with SLSI and ↑ indicates the positive relationship with SLSI.

Estimation of Sustainable Livelihood Security Index: An Indicator Approach

The present study has adopted an indicator approach to developing a sustainable livelihood security index (SLSI). The adopted method has the capability to overcome some of the difficulties of incommensurability associated with the combination of different types of data, and how the approach can be applied at a variety of scales (Eriksen and Kelly, 2006). Through the development of nested index values, more reliable and robust coverage of large areas can be achieved, and we provide an indication of how this could be done. Application of SLSI at administrative and community scales can help in identifying human populations at major risk and as a result, resources can be targeted towards those most in need. These indicators are selected as representatives of focal development policy objective, and a stepwise method for addressing the livelihood security, development linkages, and the economic, social and environmental dimensions (Halsnas and Trarup, 2009).

Using Iyenger and Sudharshan (1982) methodology, indicators were first normalised to the scale of zero (0) and one (1), premised on their functional relationship with the dimension. The indicator has a positive relationship with SLSI, then equation (1) was employed.

$$Y_{ij} = \frac{K_{ij} - \quad Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})}$$

Where, Y_ij is the index for the ith indicator related with jth ACZ, K_ij is the actual/observed value of the ith indicator for the jth ACZ,Max(X_{ij}) and Min(X_{ij}) is the maximum and minimum value of ith indicator among all the L (I= 1………9) ACZs, respectively. If the indicator has a negative functional relationship with SLSI, then equation 2 was employed.

$$Y_{ij} = \frac{Max(X_{ij}) - K_{ij}}{Max(X_{ij}) - Min(X_{ijk})}$$

Weight

The assignment of the appropriate weight for different components is an important issue in the construction of an index. Therefore, using equation (3 & 4), weights were calculated.

$$[W_i = \frac{K}{\sqrt{Var(Cid)}}]$$

$$[K = \frac{1}{\left\{\frac{1}{\Sigma_{i=1}^{n}\sqrt{Var(Cid)}}\right\}}]$$

Where, 'Wi' denotes the weight, Var(Cid) is variance of Y_{ij}. Weight is multiplied in the index value calculated in equation 1 or 2 as follows:

$$Z_j = \frac{\sum_i^k Y_{ij} * W_i}{\sum_i^k W_i}$$

Z_{jis} the index score for the jth ACZ; W_i is the weight corresponding to ith indicator; k is the total number of indicators; and $\Sigma_i^k W_i$ is the summation of weights. The index value close to zero (0) shows lower livelihood security status and the index value close to one (1) shows higher livelihood security.

Results

Infrastructure Security Index (ISI)

Infrastructure services are the core aspect related to sustainable development. The infrastructure security status revealed that Bundelkhand followed by Vindhyan and South-western semi-arid zones have the least infrastructure security whereas the Western plain, followed Mid-western plain and Bhawar and Trai plain zones have the highest infrastructure security (Table 2). Cross-indicator analysis revealed that the population in Bundelkhand zone have the least access of all seasonal houses (only 6 per cent) followed by banking facilities (only 5 per cent of the population has a membership of agricultural credit societies). Similarly, least access to medical (only 39 per cent of the population has access to public and private medical services), sanitation (only 18 per cent of the population has sanitation facility within the premises) and cooking facilities (nearly 80 per cent of the population relies upon forest resources for cooking) were the main influencing indicators for lowest infrastructure security in Bundelkhand zone.

On the other hand, better communication facility (98 per cent of the population has access to public and private communication services), followed by the power supply (more than 90 per cent of the population has access of electricity in their houses) and drainage facility (more than 80 per cent of the population has all seasonal drainage facilities) were main contributing indicators for highest infrastructure security index in the Western plain zone.

Table 2: Agro Climatic Zone-wise Infrastructure Security Index

Indicators	Bhawar and Terai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Kutcha House	0.106	0.065	0.097	0.050	0.078	0.093	0.120	0.033	0.079
Semi-Pucca House	0.106	0.199	0.221	0.107	0.166	0.223	0.074	0.236	0.127
Pucca House	0.823	0.736	0.682	0.843	0.756	0.684	0.806	0.731	0.795
Education Insti.	0.730	0.818	0.841	0.796	0.843	0.830	0.839	0.643	0.734
Medical Services	0.565	0.396	0.494	0.382	0.436	0.494	0.389	0.359	0.477
Post Office	0.090	0.169	0.175	0.191	0.137	0.164	0.286	0.130	0.158
Telephone	0.838	0.768	0.743	0.791	0.760	0.696	0.743	0.851	0.984
Transport Services	0.323	0.336	0.379	0.362	0.364	0.383	0.371	0.498	0.411
Banking Services	0.030	0.044	0.063	0.048	0.057	0.050	0.063	0.054	0.055
Agri. Credit Society	0.621	0.057	0.077	0.063	0.071	0.077	0.077	0.064	0.058
All Seasonal Road	0.579	0.642	0.755	0.666	0.664	0.748	0.793	0.738	0.589
Power Supply	0.935	0.846	0.928	0.930	0.956	0.935	0.948	0.843	0.933
Drainage Facility	1.000	1.000	0.933	1.000	1.000	1.000	0.714	1.000	0.857
Population Density	0.460	0.130	0.402	0.335	0.264	0.610	0.324	0.338	0.172
Regulated Markets	0.234	0.281	0.454	0.433	0.639	0.556	0.310	0.333	0.468
Veterinary Insti.	0.364	0.558	0.372	0.466	0.350	0.436	0.327	0.559	0.612
Garbage Collection	0.362	0.341	0.341	0.339	0.644	0.373	0.208	0.412	0.548
Sanitation Facility	0.500	0.181	0.309	0.256	0.425	0.340	0.341	0.225	0.578
Clean Energy	0.310	0.200	0.298	0.232	0.342	0.222	0.335	0.211	0.529
Drinking Water	0.556	0.639	0.589	0.463	0.650	0.371	0.532	0.333	0.429
Slum Population	0.041	0.141	0.124	0.210	0.168	0.124	0.262	0.118	0.263
Infrastructure Security Index	**0.456**	**0.407**	**0.442**	**0.427**	**0.465**	**0.448**	**0.422**	**0.415**	**0.469**
Rank	**3**	**9**	**5**	**6**	**2**	**4**	**7**	**8**	**1**

Source: Authors Estimation, 2020. Note: for Var_1 to Var_21 see Table 1 (Infrastructure security index)

Agricultural Sustainability Index (ASI)

In a rural-based economy like Uttar Pradesh, agriculture sustainability has key determinants for sustainable development. The agricultural sustainability status revealed that Bundelkhand followed by the Western plain and Bhawar and Terai plain zones were least sustainable whereas the Eastern plain followed by Vindhyan and North-eastern plain zones were highly sustainable (Table 3). In-depth analysis of the rational indicators revealed that the least area under the surface irrigation (only 10 per cent of farmers using the canal and tank water for irrigation) followed by least storage capacity (only 18 per cent of the population having the storage capacity to store farm products) and least irrigated area (more than 70 per cent of the cropped area under rainfed farming) were the main influencing indicators for lowest agricultural sustainability in the Bundelkhand zone. On the other hand, least marginal farmers (only 42 per cent of the marginal farmers) followed by highest crop-livestock management (more than 80 per cent of farmers having livestock) and higher irrigation intensity (120) were the main contributing indicators for highest agricultural sustainability in the Vindhyan zone.

Table 3: Agro Climatic Zone-wise Agricultural Sustainability Index

Indicators	Bhawar and Trai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Agricultural Labour	0.345	0.228	0.307	0.342	0.284	0.392	0.324	0.370	0.201
Cultivators	0.340	0.324	0.302	0.284	0.388	0.313	0.34	0.199	0.196
Storage Capacity	0.333	0.148	0.227	0.363	0.297	0.189	0.246	0.660	0.226
No. of Tractors	0.438	0.374	0.355	0.430	0.541	0.328	0.444	0.545	0.374
Livestock	0.813	0.86	0.854	0.869	0.731	0.875	0.847	0.801	0.825
Rainfed Area	0.179	0.323	0.353	0.272	0.299	0.313	0.556	0.534	0.297
Watershed Area	0.355	0.463	0.363	0.430	0.441	0.512	0.489	0.418	0.342
Irrigation Intensity	0.520	0.406	0.419	0.485	0.280	0.545	0.653	0.534	0.522
Surface Irrigation	0.048	0.106	0.231	0.476	0.461	0.322	0.221	0.083	0.250
Un-irrigated Area	0.200	0.167	0.160	0.182	0.134	0.217	0.241	0.114	0.296
Marginal Farmers	0.697	0.699	0.814	0.883	0.775	0.839	0.604	0.786	0.719
Marginal Area	0.321	0.325	0.462	0.589	0.401	0.516	0.233	0.383	0.327
Agricultural Sustainability Index	**0.382**	**0.369**	**0.404**	**0.467**	**0.419**	**0.447**	**0.433**	**0.452**	**0.381**
Rank	**7**	**9**	**6**	**1**	**5**	**3**	**4**	**2**	**8**

Source: Authors Estimation, 2020. Note: For Var_1 to Var_12 see Table 1 (Agricultural security index).

Economic Security Index (ESI)

The economic security index shows that the Bundelkhand followed by North-eastern plain and South-western semi-arid zones have the least economic security, whereas Eastern plain followed by the Western plain and Vindhyan zones have the highest economic security (Table 4). Cross-indicator analysis revealed that the least number of well-trained farmers (only 4 per cent of farmers have taken formal agricultural training) followed by the least income from agriculture and least share of non-farm income (only 25 per cent of the population employed in MGNREGA) were the main influencing indicators for lower economic security in Bundelkhand zone. On the other hand, higher literacy rate (nearly 70 per cent) followed by a higher share in income from the farm and allied sectors were main influencing indicators for the highest economic security in the Western plain zone.

Table 4: Agro Climatic Zone-wise Economic Security Index

Indicators	Bhawar and Terai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Agri. Income	0.385	0.295	0.488	0.570	0.000	0.267	0.358	0.456	0.593
Income from Cereals	0.433	0.216	0.461	0.632	0.420	0.220	0.369	0.417	0.566
Income from Livestock	0.415	0.328	0.465	0.446	0.328	0.489	0.465	0.653	0.458
Income from Forestry	0.351	0.344	0.177	0.510	0.425	0.495	0.336	0.131	0.335
Income from Fishing	0.351	0.270	0.365	0.232	0.566	0.216	0.209	0.534	0.389
Income from Mining	0.441	0.228	0.326	0.454	0.629	0.136	0.479	0.373	0.287
Per Capita Income	0.522	0.349	0.352	0.454	0.475	0.369	0.172	0.359	0.420
Per Capita Expenditure	0.498	0.289	0.511	0.450	0.500	0.275	0.349	0.505	0.468
Literacy Rate	0.613	0.686	0.664	0.672	0.579	0.615	0.690	0.650	0.676
MGNREGA	0.155	0.225	0.29	0.220	0.194	0.231	0.232	0.204	0.206
Pop. Below Poverty Line	0.062	0.333	0.366	0.421	0.360	0.342	0.266	0.363	0.413
Training in Agriculture	0.001	0.004	0.006	0.004	0.005	0.008	0.004	0.004	0.005
Economic Security Index	**0.352**	**0.297**	**0.373**	**0.422**	**0.373**	**0.305**	**0.327**	**0.387**	**0.401**
Rank	**6**	**9**	**5**	**1**	**4**	**8**	**7**	**3**	**2**

Source: Authors Estimation, 2020. Note: for Var_1 to Var_12 see ttable 1 (Economic security index).

Social Security Index (SSI)

In a diverse structural society like Uttar Pradesh, social security is the main pillar of sustainable development. The social security index revealed that Bundelkhand followed by Central plain and Eastern plain zones have the least social security, whereas Western plain followed by Bhawar and Terai plain and Vindhyan zones have the highest social security (Table 5). In-depth analysis of indicators revealed that the least population having health insurance (only 0.3 per cent) followed by least industry workers (only 0.5 per cent) and high female-headed households (25 per cent) were the main influencing indicators for least social security in the Bundelkhand zone. On the other hand, higher non-industry workers (57 per cent) followed by health insurance (7 per cent) and out-migration ratio (8 per cent) were main contributing indicators for higher social security in Western plain zone.

Table 5: Agro Climatic Zone-wise Social Security Index

Indicators	Bhawar and Terai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Industry workers	0.052	0.051	0.056	0.077	0.050	0.054	0.061	0.088	0.053
Non workers	0.687	0.608	0.654	0.665	0.685	0.668	0.686	0.652	0.679
Female-Headed HHs	0.129	0.075	0.125	0.098	0.138	0.093	0.076	0.191	0.143
Sex Ratio	0.545	0.365	0.252	0.470	0.371	0.445	0.541	0.429	0.625
SC population	0.351	0.352	0.405	0.334	0.394	0.385	0.361	0.408	0.634
ST population	0.494	0.153	0.251	0.245	0.331	0.250	0.242	0.349	0.298
Out-migration Rate	0.103	0.100	0.098	0.101	0.105	0.100	0.109	0.103	0.089
Health Insurance	0.044	0.031	0.055	0.058	0.041	0.093	0.057	0.082	0.076
Social Security Index	0.301	0.217	0.237	0.256	0.264	0.261	0.267	0.288	0.325
Rank	2	9	8	7	5	6	4	3	1
Pop. Below Poverty Line	0.062	0.333	0.366	0.421	0.360	0.342	0.266	0.363	0.413
Training in Agriculture	0.001	0.004	0.006	0.004	0.005	0.008	0.004	0.004	0.005
Economic Security Index	**0.352**	**0.297**	**0.373**	**0.422**	**0.373**	**0.305**	**0.327**	**0.387**	**0.401**
Rank	**6**	**9**	**5**	**1**	**4**	**8**	**7**	**3**	**2**

Source: Authors Estimation, 2020. Note: for Var_1 to Var_8 see Table 1 (Social security index).

Food Security Index (FSI)

Food security index revealed that the Bundelkhand followed by Central and North-eastern plain zones have least food security whereas Bhawar and Terai plain followed by South-western semi-arid and eastern plain zones have high food security (Table 6). In-depth analysis of indicators revealed that least fish production followed by lower cropping intensity and lower cereals productivity were main influencing indicators for lower food security in Bundelkhand zone. On the other hand, higher cereals, pulses and oilseeds productivity followed by lower cropping intensity were the main contributing indicators for higher food security in Bhawar and Terai plain zone.

Table 6: Agro Climatic Zone-wise Food Security Index

Indicators	Bhawar and Terai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Per Capita Avail Milk	0.385	0.446	0.552	0.699	0.446	0.542	0.471	0.552	0.376
Pulses Productivity	0.641	0.508	0.400	0.623	0.584	0.554	0.711	0.434	0.454
Oilseeds Productivity	0.563	0.625	0.345	0.474	0.497	0.274	0.579	0.456	0.694
Cereals Productivity	0.646	0.431	0.426	0.381	0.408	0.478	0.486	0.445	0.340
Cropping Intensity	0.516	0.386	0.561	0.400	0.597	0.404	0.464	0.523	0.381
Fish Production	0.507	0.317	0.447	0.527	0.456	0.527	0.456	0.423	0.591
Food Security Index	**0.543**	**0.452**	**0.455**	**0.517**	**0.498**	**0.463**	**0.528**	**0.472**	**0.473**
Rank	**1**	**9**	**8**	**3**	**4**	**7**	**2**	**6**	**5**

Source: Authors Estimation, 2020. Note: for Var_1 to Var_6 see Table 1 (Food security index).

Environmental Security Index (EVSI)

Diverse agro-climatic conditions, back-to-back droughts and floods, and continuously declining water table are putting pressure on the scarce and finite natural resources (Table 7). Therefore, the present study has developed an environmental security index for different ACZs. The environmental security index revealed that Bundelkhand followed by Eastern plain and Central zones have the least environmental security whereas Vindhyan followed by Mid-western plain and Western plain zones have the highest environmental security. In-depth analysis of indicators revealed that continuous increasing maximum temperature followed by least irrigated area and continuous declined water level were main influencing indicators for least environmental security in the Bundelkhand zone. On the other hand, least area affected by salinity/alkalinity, waterlogged and marshy followed by highest forest area and least number of tube wells were main contributing indicators for the highest environmental security in Vindhyan zone.

Table 7: Agro Climatic Zone-wise Environmental Security Index

Indicators	Bhawar and Terai Plain Zone	Bundelkhand Zone	Central Zone	Eastern Plain Zone	Mid-western Plain Zone	North-eastern Plain Zone	South-western Semi-arid Zone	Vindhyan Zone	Western Plain Zone
Air Quality Index	0.364	0.753	0.649	0.714	0.563	0.519	0.647	0.667	0.589
Water with Nitrate	0.635	0.168	0.246	0.294	0.453	0.573	0.262	0.580	0.540
Deep Tub wells	0.366	0.350	0.313	0.208	0.526	0.344	0.299	0.382	0.309

Water Level	0.417	0.472	0.360	0.306	0.688	0.143	0.653	0.444	0.321
Degraded forest	0.363	0.200	0.122	0.115	0.303	0.422	0.182	0.990	0.307
Ravenous land (medium)	0.000	0.003	0.276	0.222	0.178	0.417	0.218	0.510	0.183
Land with Dense Scrub	0.341	0.165	0.137	0.205	0.301	0.255	0.243	0.643	0.433
Land with Open Scrub	0.366	0.203	0.256	0.307	0.613	0.327	0.220	0.672	0.294
Waterlogged land	0.333	0.061	0.203	0.233	0.457	0.000	0.360	0.345	0.216
Land affected by salinity	0.351	0.012	0.510	0.352	0.403	0.179	0.399	0.359	0.176
Waste/ Degraded Land	0.626	0.378	0.299	0.600	0.421	0.304	0.375	0.568	0.816
Non- Agricultural Area	0.134	0.359	0.309	0.566	0.392	0.464	0.568	0.472	0.291
Ground Irrigation	0.952	0.678	0.769	0.524	0.539	0.779	0.894	0.917	0.750
Maximum Temperature	0.587	0.833	0.602	0.611	0.579	0.540	0.580	0.640	0.666
Minimum Temperature	0.476	0.411	0.495	0.324	0.225	0.507	0.461	0.500	0.471
Rainfall	0.367	0.446	0.484	0.363	0.494	0.313	0.534	0.424	0.560
Forest Area	0.119	0.083	0.031	0.036	0.009	0.083	0.023	0.240	0.046
Environmental Security Index	**0.400**	**0.328**	**0.356**	**0.352**	**0.420**	**0.363**	**0.407**	**0.550**	**0.410**
Rank	**5**	**9**	**7**	**8**	**2**	**6**	**4**	**1**	**3**

Source: Authors Estimation, 2020. Note: for Var_1 to Var_17 see Table 1 (Environmental security index).

Health Security Index (HSI)

The health security index revealed that Bundelkhand followed by the South-western semi-arid and North-eastern plain zones have least health security, whereas Mid-western plain, followed by Western plain and Vindhyan zones have higher health security (Table 8). In-depth analysis of indicators revealed that the highest number of overweight men and women (10 per cent) and the highest infant deaths rate were the main influencing indicators for least health security in the Bundelkhand zone. On the other hand, the highest population using iodized salt (95 per cent) followed by least men whose body mass index is below normal (32 per cent) were main contributing indicators for the highest health security in Vindhyan zone.

Table 8: Agro Climatic Zone-wise Environmental Security Index

Indicators	**Bhawar and Terai Plain Zone**	**Bundelkhand Zone**	**Central Zone**	**Eastern Plain Zone**	**Mid-western Plain Zone**	**North-eastern Plain Zone**	**South-western Semi-arid Zone**	**Vindhyan Zone**	**Western Plain Zone**
Iodised Salt	0.925	0.924	0.88	0.949	0.951	0.892	0.954	0.978	0.975
Women BMI below normal	0.273	0.252	0.278	0.282	0.285	0.278	0.213	0.257	0.203
Men BMI below normal	0.317	0.259	0.268	0.259	0.326	0.283	0.220	0.254	0.218
Women who are overweight	0.171	0.15	0.113	0.136	0.173	0.135	0.185	0.134	0.239
Men who are overweight	0.102	0.106	0.081	0.130	0.102	0.110	0.142	0.095	0.176

Infant Deaths	0.231	0.114	0.382	0.200	0.326	0.207	0.144	0.365	0.314
Health Security Index	0.337	0.301	0.334	0.326	0.361	0.318	0.310	0.347	0.354
Rank	4	9	5	6	1	7	8	3	2

Source: Authors Estimation, 2020. Note: for Var_1 to Var_6 see Table 1 (Health security index).

Sustainable Livelihood Security Index (SLSI)

The multi-dimensional sustainable livelihood security index (SLSI) consists of infrastructure security, agricultural sustainability, social security, environmental security, and health security. The calculated SLSI indices for different ACZs revealed that Bundelkhand zone has the lowest livelihood security among the ACZs (Table 9) whereas Vindhyan zone has the highest livelihood security.

Table 9: Agro Climatic Zone-wise Sustainable Livelihood Security Index

Agro Climatic Zone	Infrastructure Security Index	Agricultural Sustainability Index	Economic Security	Social Security Index	Food Security Index	Environmental Security Index	Health Security Index	Sustainable Livelihood Security Index	Rank
Bhawar and Terai Plain Zone	0.456	0.382	0.352	0.301	0.543	0.400	0.337	0.396	4
Bundelkhand Zone	0.407	0.369	0.297	0.217	0.452	0.328	0.301	0.339	9
Central Zone	0.442	0.404	0.373	0.237	0.455	0.356	0.334	0.372	8
Eastern Plain Zone	0.427	0.467	0.422	0.256	0.517	0.352	0.326	0.395	5
Mid-western Plain Zone	0.465	0.419	0.373	0.264	0.498	0.420	0.361	0.400	3
North-eastern Plain Zone	0.448	0.447	0.305	0.261	0.463	0.363	0.318	0.372	7
South-western Semi-arid Zone	0.422	0.433	0.327	0.267	0.528	0.407	0.310	0.385	6
Vindhyan Zone	0.415	0.452	0.387	0.288	0.472	0.550	0.347	0.416	1
Western Plain Zone	0.469	0.381	0.401	0.325	0.473	0.410	0.354	0.402	2

Source: Authors Estimation, 2020.

Identification of Low Productive Districts

The present study has also attempted to identify the low productive districts using the productivity of cereals, oilseeds and fish data. For instance, (i) food security index for each district was calculated with reference to Uttar Pradesh, (ii) quintile estimation was used to arrange the districts into four categories, i.e. low (0-25th percentile), medium (26th -50th percentile), high (51st -75th percentile) and very high (76th -100th percentile), (iii) and region-wise distribution is also done. A total of 19 out of 75 districts were classified as low productive districts (Table 10). It can be seen that the maximum number of low productive districts, i.e. 6 out of 7 are in Bundelkhand zone, 5 out of 14 are in Central zone, and 2 each are in Eastern plain, North-eastern plain & Vindhyan zones.

Table 10: Agro-climatic Zone-wise Very Low Agricultural Productive Districts

Agro-climatic Zone	No. of Districts	Name of the District
Bhabhar and Terai Zone	0	-
Bundelkhand Zone	6	Banda, Chitrakoot, Hamirpur, Jalaun, Jhansi, Lalitpur, Mahoba
Central Zone	5	Fatehpur, Hardoi, Kannauj, Kanpur Dehat, Kaushambi
Eastern Plain Zone	2	Faizabad, Jaunpur
Mid-western Plain Zone	0	-
North-eastern Plain Zone	2	Lakhimpur Kheri, Shravasti
South-western Semi-arid Zone	2	Mahamaya Nagar, Mathura
Vindhyan Zone	2	Mirzapur, Sonbhadra
Western Plain Zone	0	-

Source: Author Estimation, 2020.

The calculated SLSI indices have also been compared with the previous studies, i.e., the studies conducted by the Planning Commission (2001) and NITI Aayog (2018) (Table 11). In 2001, the Task Force of Planning Commission had used poverty, unemployment, agricultural wage, agricultural productivity, Scheduled Caste and Scheduled Tribe population, and rural connectivity data to identify the backward districts all over India. The Task Force had identified 30 most backward districts in Uttar Pradesh. In 2018, NITI Aayog had used large-scale socio-economic and demographic data to identify backward districts all over India. The report found eight (8) most backward districts belongs to the Uttar Pradesh. Therefore, the present study has made an attempt to match the results with the Planning Commission and NITI Aayog findings. Table 11 revealed that out of 30 districts identified by the Planning Commission, the results from 11 go with the present study. Further, out of the eight districts identified by NITI Aayog, six have matching results in the present study. Aforesaid findings show the practicality of present study in a broader sense.

Table 11: Agro-climatic zone-wise Comparison of Backward Districts Identified by Planning Commission, NITI Aayog

Agro-climatic Zones	**Task Force, Planning Commission (2001)**	**NITI Aayog (2018)**	**Present Study**	**Matched**	
				Taskforce Planning Commission	**NITI Aayog**
Bhabhar and Terai Zone	0	0	0	0	0
Bundelkhand Zone	6	1	4	4	1
Central Zone	6	1	5	2	0
Eastern Plain Zone	3	1	6	1	0

Source: Authors Estimation, 2019.

Mid-western Plain Zone	1	0	1	0	0
North-eastern Plain Zone	11	4	7	3	4
South-western Semi-arid Zone	1	0	0	0	0
Vindhyan Zone	2	1	1	1	1
Western Plain Zone	0	0	2	0	0
Total	**30**	**8**	**26**	**11**	**6**

Source: Authors Estimation, 2020.

Conclusion and Policy Recommendations

The present study has made an attempt to develop a practical, innovative and ready-to-use multidimensional livelihood security index for nine ACZs in Uttar Pradesh. With multidimensional speciality, it can work as a commanding tool for verifying the necessary conditions for sustainable development in a functional unit of development planning. As a strategy tool, SLSI identifies not only the ACZs requiring immediate attention but also the specific thematic areas in which the efforts could be focused to attain livelihood security. For instance, the Vindhyan zone has the highest SLSI ranking but it has the second lowest position in infrastructure security and 6th position in food security, requiring intervention for improving the infrastructure and food security status in the ACZ. Bundelkhand zone has reported the lowest among the ACZs in all dimensions of sustainable livelihood security, requiring immediate policy interventions to combat adverse impacts of climate change (continuously increasing temperature). The multidimensional SLSI helps to focus on the conflicts and the potential synergy between infrastructure, agriculture, economic, social, food, environment and the health dimensions of sustainable development.

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Mainstreaming climate adaptation in Indian rural developmental agenda: A micro-macro convergence

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ABSTRACT

Vulnerability of agriculture to climate shocks and its consequences on farm livelihoods and food security is well recognized. Mainstreaming climate adaptation into policy landscape is a must for achieving the pathway to sustainable development. The approach envisages grass-root and climate perspectives to bring about developmental interventions for rural poor and small farm holders. Even though macro-level planning is necessary and useful, the coping mechanisms across different socio-economic and agro-climatic settings should be recommended at micro-level especially in developing nations. Responses of resource poor farmers to weather abnormalities are often rendered ineffective on account of several barriers to adaptation. Keeping this in view, we attempted to review the potential strategies adopted by the farmers, with a greater focus on constraints to adaptation in order to feed into the policy options of the Government. The authors articulate that the micro-level inferences from natural resource management, agriculture research and development, infrastructure and human capital across the space should be integral part of the climate adaptation planning. Moreover, the paper demonstrates how the developmental interventions spread across different verticals of the government can mutually address both the rural development and climate adaptation considerations. It is also construed that strengthening the role and capacity of local institutions in assembling grass-root information and in implementation of programmes is crucial for effectively addressing vulnerability to both the climatic and non-climatic factors. In nutshell, the paper aims at assisting development practitioners and policymakers in devising an effective approach towards mainstreaming climate adaptation in the existing rural developmental architecture.

1. Introduction

The increasing intensity of climatic risks on food and livelihood security emphasizes the transformational pathway towards sustainable development. The growing evidences confirm that agriculture sector is heavily experiencing the effect of changing climatic conditions (Lobell et al., 2011; Auffhammer and Schlenker, 2014; Campbell et al., 2016; Khanal and Mishra, 2017), severity of which is expected to increase in the near future; with developing nations being the most affected (IPCC, 2012, 2014). Weather aberrations and sudden onset of extremes (dry spells, droughts and floods) adversely affects crop yields through outbreak of pest and diseases (Easterling et al., 2007; Gornall et al., 2010), changes in soil fertility (Tang et al., 2008; Clair and Lynch, 2010), moisture content and most importantly water quality and resources (FAO, 2011; Misra, 2014, Malek et al., 2018). Such climate induced production risks not only deters food security and nutrition but also heightens the pressure on socio-economic stability of rural

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economies thereby aggravating poverty, unemployment, migration (Singh et al., 2014; FAO, 2016) and social conflicts in the region. The magnitude of climate risks however differs among the households, premised on their existing coping capacity, social acceptability to adaptations, collective coherency and in-situ economic developments (Adger, 2003). Agriculture sector in India contributes 14% to Gross Domestic Product (GDP) and remains a major livelihood support to more than 50% of the total workforce. The system is heavily dependent on south-west monsoon (June to September), which is critical for more than half of the food production around the year. High reliance on rainfall for irrigation, small and fragmented land holdings and limited technical and financial resource base (Acharya, 2006; Khan et al., 2009; Jain et al., 2015; Patnaik and Das, 2017) makes Indian farm households highly susceptible to weather abnormalities. Over the years prolonged breaks in southwest monsoon have increased the frequency of droughts (Udmale et al., 2015; Zhang et al., 2017; Choudhury and Sindhi, 2017) with consecutive drought periods being witnessed in different parts of the subcontinent. In analyzing spatial trend and varibility of droughts, Mallya et al. (2016) showed a shift in droughts towards agriculturally important coastal south-India, central Maharashtra, and Indo-Gangetic plains. Under different temperature and precipitation scenarios studies have also shown a significant fall in the productivity of major crops like rice, wheat, maize and millets in the country (Sanghi and Mendelsohn, 2008; Guiteras, 2009; Lobell et al., 2012; Auffhammer et al., 2012, Kumar et al., 2014; Gupta et al., 2014). Fluctuations in crop yields affects food availability, prices and farm revenues which undermine socio-economic progress in the rural economy. For India, annual agricultural income losses due to climate change is estimated in the range of 15%–18%, rising to 20%–25% for unirrigated areas (GOI, 2017). Climate variations are particularly more damaging for the farm households in semi-arid tropics, where rainfall is highly variable, soil fertility is low and drought are recurrent phenomena (Bantilan and Anupama, 2006; Singh *et al.*, 2014). Fostering the process of adaptation is therefore a plausible option to deal with extremes and minimizing vulnerability of the marginalized communities in short to medium run.

Farmers possess repository of traditional knowledge about the nexus of climate and agriculture that guide their adaptation decisions to limit the losses against the uncertainties caused by season-to-season variation (Jodha et al., 2012). In such a system, farm decisions or choices to risk management are channeled through mutually reinforcing preconceived notions, beliefs and social obligations, which could be sub-optimal. Capacities to cope or adapt to weather abnormalities and livelihood risks are influenced by wide range of socio-economic factors, prevalence of infrastructure facilities, access to assets and the ability to harness and share knowledge (Patnaik and Das, 2017; Singh et al., 2018b). The willingness and participation of state and institutions in agriculture dependent economies is therefore, essential in bringing the desired behavioral change among the rural households in the way they perceive and act to climatic changes. Moreover, strengthening farmers capabilities and making their livelihoods more resilient to the unpredictable weather perils, necessitates the need to mainstream climate adaptation into the rural development and poverty alleviation programmes (Dessai and Wilby, 2011; Agrawala and Lemos, 2015). Mainstreaming climate adaptation, ostensibly a multi-dimensional approach postulates convergence between micro and macro level to address the various layers of constraints faced by the rural households.[1] Planning at macro level largely focuses on aggregate data with less factoring for local requirements and needs. Inclusion of ground realties and engagement of village/local communities is central in devising appropriate locally tailored interventions and enhancing need-based adaptive capacity of the farmers (Singh et al., 2014, 2018a).

The growing body of literature recognizes adaptation to climate change as a set of strategies that are closely intertwined with the developmental activities (TERI, 2005; Smit and Pilifosova, 2003; Agrawala and Lemos, 2015). In the context of agriculture, programmes and strategies catering to the rural development and advancement are the major drivers for enhancing the resiliency of agriculture ecosystem (FAO, 2016; Singh et al., 2017, 2018a). Building upon these considerations, we reviewed climate induced coping mechanisms adopted by the farmers and several barriers to adaptation, categorized into relevant thematic groups. We also analyzed the adaptation-development continuum in an attempt to link the identified constraints faced by the rural/farm households to adaptation with the appropriate policy options in the rural developmental framework. This calls for a micro and macro convergence along with significant role of government policy interventions in addressing the dual challenge of development and climate adaptation in agriculture in the developing countries especially in India.

2. Micro-level coping mechanisms

There are several risk management strategies adopted by the rural households, largely spontaneous and reactive against climate induced stresses. These responses can be both social and technical in nature based on household resource endowment, knowledge (Malik and Rathore, 2012; Dinar and Jammalamadaka, 2013; Wood et al., 2014) and myriad contextual factors. From policy perspective, it is crucial to understand, what sort of measures are being adopted at the micro-level and their relevance in terms of future sustainability. Following review on adaptation strategies at micro level includes natural resource management, non-farm activities and sociological perspective.

2.1. Crop-level and natural resource management adaptations

In response to the perceived variations in temperature and irregular/delayed monsoon, farmers are making shifts in planting schedules and harvesting dates/timings (Salau et al., 2012; Udmale et al., 2014; Varadan and Kumar, 2014) and adopting improved

[1] Here micro level refers to the household and village level information pertaining to climate impacts, perceptions and beliefs, behavioral pattern of the farmers, their actions and interactions to develop responses and barriers that restrict the possible coping and diversification options. Macro level on the other hand is multilayered policy chain from national to state to local/ district level.

crop varieties which are less water consuming, high yielding and drought resistant (Roy and Hirway, 2007; Udmale et al., 2014, Singh et al., 2018a). Crop diversification/intercropping/mixed cropping (Jain et al., 2015; Singh et al., 2014; Reddy et al., 2015) are the most identified agronomic practices among the Indian farmers to climatic variations. As opposed to mono-cultivation, intercropping and mixed cropping results in greater productivity and profitability especially in the rainfed/dry land regions (Chandra et al., 2010, Singh et al., 2015; Khanal and Mishra, 2017). In addition, such systems are now seen as environmentally more sustainable adaptation measures that can efficiently utilize the available resources. Shah and Ameta (2008) in Dhala located in the state of Rajasthan and Hegde et al. (2017) in Gulbarga district, Bangalore and Kolar district, Karnataka shows that farmers are opting for the package of organic practices such as green manuring, mulching, composting and zero budget net farming as measures conserving soil properties, utilizing less water and yielding more output than conventional strategies. In the semi-arid regions of India, farmers were found to have a greater preference for less risky crops (Khanal and Mishra, 2017). Planting trees on farmlands are also being practiced among several villages as significant livelihood backup to crop failure (Kattumuri et al., 2015). In Sangrur district of Punjab state, farmers were adopting improved farm machinery such as zero tillage drills, rotavators, laser land levelers, and happy seeders that can potentially enhance input efficiency, conserve soil and water resources, as well as address issue of crop stubble burning (Ojha et al., 2014). Against irregularities in monsoon, in some of the villages of Maharashtra and Andhra Pradesh, there were creation of water saving structures such as farm ponds, furrow channels and check-dams (Banerjee, 2014; Vedeld et al., 2014; Rao et al., 2017). Application of drip irrigation however, remains low in the country with less than 5% of the net sown area (Dev, 2016) owing to high transaction costs and technical complexities. There is also an increasing exploitation of groundwater due to under-provision of irrigation infrastructure, incentives in the form of electricity subsidy and lack of institutional regulations (Rajagopal and Jayakumar, 2006; Jodha et al., 2012; Bantilan et al., 2013).

2.2. Off-farm/non-farm activities

For minimizing the impact of environmental risks and ensuring consistency in domestic consumption pattern, rural households often engage in diverse livelihood-generating activities (Davis et al., 2010; Patnaik and Das, 2017). Apart from crop cultivation, dairy livestock, poultry and cattle rearing are often observed as common subsidiary activities among agriculture households (Kumar et al., 2007; Kattumuri et al., 2015). However, given the climatic variations and consequent increase in heat stress, sustenance of earnings from livestock is under threat. Farmers also engage themselves in casual/part-time work or self-employed ventures to face any risky situation. Between 1999–2000 and 2011–2012 it is found that, rural non-farm employment in India increased by 12 percentage points (Saha and Verick, 2016). Bhatta et al. (2015) in their study stated that in Bihar, a large proportion of the farm households were engaged as wage labourers either on other farm lands or in non-farm sectors. In some villages occupational diversification includes opening up of small shops like provision store, repair shops, etc. (Tripathi and Mishra, 2017). Participation in employment generating interventions of the government, most notably MGNREGS[2] (Udmale et al., 2015; Banerjee et al., 2013; Singh et al., 2018b) has emerged as a prominent diversification option among the rural households.

Transitory or seasonal migration to urban agglomerations in search of work is seen as an important response strategy by the poor households against deprivations caused by weather shocks (McLeman and hunter, 2010; Bhatta and Aggarwal, 2016, Singh et al., 2018b; Rama Rao et al., 2018). Some recent researches have tried to establish the linkage between weather variations leading to changes in crop yields and out-migration in India. For instance, using district level data Viswanathan and Kumar (2015) showed that a 1 per cent decline in productivity of rice and wheat leads to nearly 2 and 1 per cent increase in the rate of out-migration from a state. Another study by Dallmann and Millock (2017) found that an increase in frequency of droughts especially in agricultural states increases the rate of inter-state migration. Remittances sent by people working in town and cities, back to village can be an important source for building requisite assets to deal with extremes.

2.3. Social networks and other measures

There are also evidences that to compensate for erosion in income and meeting consumption requirements, farmers resort to higher borrowing majorly from informal sources (Bantilan and Aupama, 2006; Singh et al., 2018b). Additionally sale or mortgage of livestock, land and other farm assets during drought conditions are other mechanisms adopted to cope up with distress (Selvaraju et al., 2006, Jodha et al., 2012; Varadan and Kumar, 2014, Singh et al., 2016). Despite, an effective risk mitigation instrument, very small segment of the agricultural households insure their crops (GOI, 2013). Such low rate of crop insurance has been largely attributed to poor awareness, delayed compensations and inadequate crop failure assessments. Further, in the villages of Andhra Pradesh, high dependence on Self Help Groups (SHGs) among women was observed for financial needs and access to better inputs and technology than in the villages of Maharashtra (Singh et al., 2015). Adherence to social traditions and festivities form a significant aspect of village economics in India and a huge amount of money is spent on these due to strong beliefs and social obligations (Singh et al., 2018a). However, there seems to be a reduction on such practices due to higher educational level and increased economic well being inspite of growing weather uncertainity.

[2] Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), a flagship programme of the Government of India mandates at least 100 days of guaranteed wage employment in a financial year to every rural household whose adult members volunteer to do unskilled manual work.

Table 1
Typology of barriers to climate adaptation.

Major constraints	Issues to climate adaptation
Technological	• Limited availability of drought tolerant varieties and location specific technologies (Niranjan et al., 2013; Suddhiyam et al., 2013) • Limited research on climate change and adaptation in agriculture and its various socio-economic dimensions • Inadequate funds for agriculture R&D activities (Muller and Shackleton, 2014; Menike and Arachchi, 2016) • Under-development of irrigation and water efficient infrastructure in rainfed areas (Elliott et al., 2014; Panda, 2016; Rama Rao et al., 2018) • High initial cost of investment in water saving technologies like micro irrigation, farm ponds, etc (Palanisami et al., 2011; Rao et al., 2017)
Economic	• Small and fragmented land holding (Planning Commission, 2007; Kumar et al., 2013; Ojha et al., 2014) • Affordability and timely availability of farm inputs (seeds, fertilizers) (Eakin, 2000; Mertz et al., 2009; Varadan and Kumar, 2014; Bhogal, 2016) • Inadequate provision of formal financial facilities (credit and insurance) to the rural poor and small and marginal farmers (Deressa et al., 2009; Jantarasami et al., 2010; Satishkumar et al., 2013; Moser and Ekstrom, 2010; Vedeld et al., 2014; Ndjeunga et al., 2015; Bhave et al., 2016) • Inefficiencies in agriculture marketing and lack of market access to the farmers (Bryan et al., 2009;Vedeld et al., 2014; Elum et al., 2017), lack of post–harvest and storage facilities (Banerjee et al., 2013, Bhogal, 2016) • Power shortage (Ojha et al., 2014)
Institutional	• Policy implementation gaps and poor inter-institutional coordination to implement adaptation actions (Spires et al., 2014; Azhoni et al., 2017) • Insecure and poorly defined property rights (GIZ, 2013) • Weak institutions for collating and synthesizing data (GOI, 2010) • Limited competency of policy makers and other stakeholders in understanding climate change and its integration with the agriculture R &D and developmental programmes(Revi et al., 2015) • Weak collective actions, limited participation of SHGs and other state agencies in coping towards climate affects (Jodha et al., 2012; Bantilan et al., 2013)
Informational	• Lack of information on credit/insurance facilities and various financial reliefs to the rural farm households (Nhemachena and Hassan, 2007; Deressa et al., 2009, 2011; Bantilan et al., 2013; Rama Rao et al., 2018) • Insufficient farm household/State level data base to analyse/understand climate impact, vulnerability and coping capacity (Niranjan et al., 2013; Patra, 2014). • Poor reliability of grass-root level information and lack of computational capacity (Meybeck et al., 2012) • Lack of information on climate changes, adaptation techniques and weather forecast at the farm level (Deressa et al., 2009;Ozor et al., 2010; Francisco et al., 2011, Taraz, 2017) • Poor dissemination/extension of technology (Satishkumar et al., 2013) • Unawareness on government welfare and relief programmes (Singh et al., 2012, 2018a)
Social/Cultural	• Under developed human capital (education) which restricts farmers ability to adopt appropriate measures and adaptation strategies (Nelson et al., 2009;Wright et al., 2014) • Societal norms and obligations preventing adoption of new techniques, superiority of traditional practices, low self-efficacy and perception of inability to effectuate change, political and social marginalisation and discrimination. (Adger et al., 2009; Jones and Boyd, 2011; Satishkumar et al., 2013;Le Dang et al., 2014)

3. Micro-level barriers to adaptation decision-making

Grass-root responses to weather variability and extremes are often rendered ineffective due to several constraints that impede their effective implementation (Bryan et al., 2009; Deressa et al., 2009). For devising plausible adaptation and livelihood strategies, it is crucial to systematically assess and understand the dynamics of obstacles that translates into weak coping capacity and prevents adoption of improved practices. After exploring the literature, a large number of factors ranging from social/cultural, institutional, informational, technological, financial and infrastructural (Smit and Pilifosova, 2003; Ekstrom and Moser, 2014) were identified that hinders adaptation among rural farm household in India and other developing countries (Table 1).

4. Mainstreaming climate change adaptation

Capacity to adapt is multifaceted and dynamic in nature. It is now widely acknowledged that it is the state of development that can reduce exposure and sensitivity of rural households to climate impacts and regulate their capacity to manage risks (Ayers and Huq, 2009). Broad spectrum of activities ranging from social, economic, technological, infrastructural and institutional arena that promotes sustainable development in rural areas also encourages adoption of better agricultural practices and opportunity to diversify livelihood. The close linkage between climate adaptation and development necessitates addressing the two in an integrated manner (Ayers and Dodman, 2010; Fankhauser and Schmidt-Traub, 2011) to achieve climate resilient pathways. One such way of integration is through the concept of mainstreaming climate adaptation into the development programmes and actions at different scales of national, sub-national and local level. Viewing development planning through climate lens strengthen the capacity of developmental activities in supporting equitable growth and sustainable livelihoods in the long run. In agriculture planning, this requires reshaping the existing programmatic interventions to realign climate change, food, nutrition and livelihood dimensions (FAO, 2016). In addition, convergence between macro and micro level decision-making culture is a must for successfully feeding the cross-scale and cross-sectoral issues and opportunities into the policy realm.

India's decentralized planning process provides a multi-level institutional platform for such convergence, with information

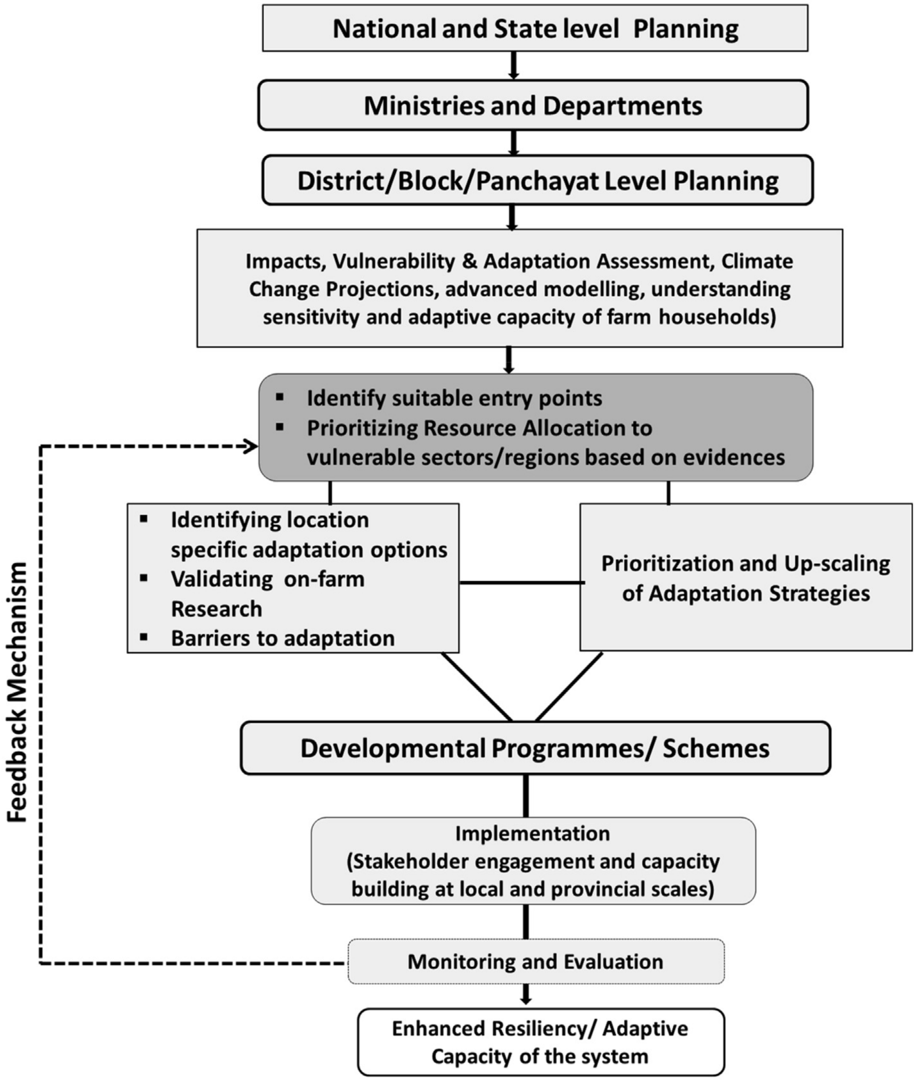

Fig. 1. Framework for mainstreaming climate adaptation into developmental framework (Authors illustration).

percolating from the village/panchayat/district to the state and national level (Fig. 1). Coordination within and between multiple institutions and stakeholders is central to the mainstreaming agenda. This proves to be more challenging in the Indian democratic context, with large number of ministries and departments having overlapping domains and objectives.

In such a system of governance, each ministry/department needs to carry an independent climate assessments based on repository of collated grass-root information for preparation of both the current and future climate risks. It is argued that the participation of local communities and institutions is crucial in assessing vulnerability, impacts and constraints, for developing effective responses to climate change. However, for determination of suitable adaptation options, strategies must be scientifically evaluated, which necessitates a two-way communication across institutions and stakeholders for ensuring complementarity between actions and avoiding possible maladaptation. Next suitable entry points in the form of developmental programs need to be identified for infusing both the climatic considerations, barriers and prioritized adaptations strategies. One major aspect of mainstreaming process is allocation of budget for climate change adaptation actions and implementation. There remains a considerable uncertainty over funding mechanism owing to the close relationship between adaptation and development. It is pertinent that allocations should be provisioned more towards climate-oriented interventions and to more vulnerable sections/regions, than on strategies completely coinciding with developmental actions, as adaptation and development are *sine qua non*. Moreover, strong local monitoring and evaluation is important for assessment of adaptation strategies, for successfull management of climate risks.

5. Micro-macro level convergence

Based on the barriers identified in the earlier section, following are some of the policy options in the current developmental

Table 2
Technological and informational Issues to adaptation and related Schemes.

Barrier	Issue for adaptation	How	Who	Schemes
Technological/ informational Constraints	Poor dissemination of technology and incompetency of extension agents	• Short-term & long-term training of extension agents • Collaboration with private/commercial companies • Information and Communication Technologies • Promote the role of NGOs and other providers/ agencies to operate in the entire country, ensuring they provide complementary services	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare, Department of Agricultural Research and Education*), Department of Science and Technology, NABARD	• National Mission on Strategic Knowledge for Climate Change • National Mission on Sustainable Agriculture • National Innovations on Climate Resilient Agriculture • National Mission on Agricultural Extension and Technology- Sub-Mission on Agricultural Extension • Kisan Call Centers • Krishi Vigyan Kendras • National Adaptation Fund
	Lack of information on climate changes, adaptation techniques Insufficient funds for agriculture R&D activities	• Conduct agricultural research to develop practices & invest in extension to promote the practices • Conduct research to determine new precipitation & temperature patterns and forecasts	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare, Department of Agricultural Research and Education*), Ministry of Science and Technology (*Department of Science and Technology)*, NABARD	• National Mission on Sustainable Agriculture • National Innovations on Climate Resilient Agriculture • National Adaptation Fund
	Delayed weather and seasonal climate forecasts	• Installation of weather station at village level • Generation of data at grass-root/panchayat level • Agro-advisory providing real time data at Public and Private and NGO level • Institutional support for agro-advisory services	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare, Department of Agricultural Research and Education*), Ministry of Water Resources, River Development and Ganga Rejuvenation, Indian Meteorological Department	• National Mission on Sustainable Agriculture • National Innovations on Climate Resilient Agriculture • Flood Forecasting • Numerical Modelling of Weather & Climate • Agro-Meteorological Services Programme
	Affordability and access to farm inputs	• Improved access to subsidized seeds (stress tolerant varieties), planting material, machinery (conservation agriculture), plant protection chemicals etc.	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare*)	• Sub-Mission on Seed and Planting Material • Sub-Mission on Agricultural Mechanization • Sub-Mission on Plant Protection and Plant Quarantine

Note: Adopted and modified from Singh et al. (2017), (2018a).
NABARD stands for National Bank for Agriculture and Rural Development.

framework of the Government of India that can help enhance resiliency of the farm households to climate induced vulnerability and risks, directly or indirectly.

5.1. Technologies for climate smart agriculture

Generation and dissemination of real time scientific information and weather forecast is the most significant component to the development of climate smart agriculture. Programmes having multi-pronged strategy such as, National Mission on Strategic Knowledge for Climate Change, National Mission for Sustainable Agriculture, ICAR-National Innovations in Climatic Resilient Agriculture (NICRA) and National Adaptation fund are creating much needed knowledge networks and climate information system *via*, multi-level capacity building, data gathering and extensive research and development activities, facilitating climate adaptation at the farm level. Strengthening of agricultural advisory services allow enhanced adoption of improved farm practices and promote informed agriculture operations. To raise awarenes and capacitate farmers knowledge of possible climate risks and adaptation should be factored into the ongoing extension units such as National Mission on Agriculture Extension, *Krishi Vigyan Kendra* (KVKs) and *Krishi Call Center* at the local or regional level. Further, local crop contingency plans can be put in place using modern tools of remote sensing and Geographical Information Systems (GIS), analyzing changes in land use and land cover (Table 2).

5.2. Natural resource management

Encouraging adoption of *in situ* water harvesting technologies, promotion of micro-irrigation (drip and sprinkler), combined with maintenance and creation of drought proofing infrastructure in Public Private Partnership (PPP) mode can reduce water related risks. Schemes like *Pradhan Mantri Krishi Sinchayee Yojana*, National Water Mission, National Mission on Sustainable Agriculture and MGNREGS while expanding irrigation coverage can help in achieving 'per drop more crop' agenda in the country. Besides, there is need to strengthen participatory irrigation management (PIM) and water user associations (WUAs) for establishing collective responsibility among the users and ensuring economy and equity in water use. As described in Table 3, Soil Health Card, National Project on Management of Soil Health and Fertility and *Paramparagat Krishi Vikas Yojana* of Ministry of Agriculture and Farmers Welfare, promotes increased application of integrated nutrient management techniques to moderate the effect of climate change on soil. Moreover, new farming methods involving shift from use of chemicals inputs (fertilizers and pesticides) to natural farming such as Zero Budget Natural Farming (ZBN) and organic practices should be encouraged through relevant programmes.

5.3. Risk management, market access and diversification

Formulating viable weather-based crop insurance products requires extensive research for developing effective models of risk assessment and management. Recently launched, *Pradhan Mantri Fasal Bima Yojana* by the government contains uniform premium rates for different crop seasons and broader risk coverage in the form of yield loss, post-harvest loss and localized calamities to protect farmers against non-preventable risks. There is also mandatory use of advanced technologies (like remote sensing, GIS, etc.) for faster detection of crop losses and claim settlements. However, timely conduct of crop cutting experiments to estimate crop losses and collation of farm level data is crucial for the success of the program. Lack of access to formal financial facilities to the marginalized communities has been the most cited barrier in the field based studies to the process of adaptation. Subsidized interest rates and easy access to formal credit promotes adoption of progressive farm practices, high value inputs and farm mechanization. Further schemes like e-National Agricultural Market and others as shown in Table 4, aims to address markets fragmentation, price anomalies, multiple functionaries' chain and information asymmetry can significantly promote regional crop planning and help farmers diversify their income sources to high value crops. Farmers who either diversify agriculture practices or livelihood activities or both are less vulnerable to external shocks.[3] For occupational diversification rural population often lack requisite skills and education to serve other sectors of the economy. To fill this skill gaps, mega schemes of the government such National Rural Livelihood Mission, *Pradhan Mantri Kaushal Vikas Yojana, Skill India* and others can play a significant role in empowering rural population for finding suitable non-farm work. Further, the role of educational institutes and non-governmental organizations (NGOs) holds significance in breaking social and cultural barriers especially in villages by focusing on behavioural communication strategy at the grass-root level.

Moreover, social safety nets in the form of cash and kind transfer is increasingly found to be proven as possible actions that can help foster resilience to weather variability (World Bank, 2010; Castells-Quintana et al., 2018). In addition to protection, such measures promote livelihood and mechanisms to scale up and out against weather perils (Hansen et al., 2018).

6. Conclusion

Recognizing the vulnerability of Indian agriculture to climatic variability, there is an urgent need to mainstream climate adaptation into the rural policy landscape for inclusive and climate resilient sustainable development. This paper reviewed various coping

[3] There are two major forms of diversifications; agricultural diversification and livelihood diversification (FAO, 2016). Agricultural diversification involves shifting cropping pattern or promoting farm diversification via, animal husbandry, poultry and fisheries. Livelihood diversification on the other hand, blends off-farm activities with farm activities to manage risk from external factors. This includes opening small grocery shops, hotels, participation in employment schemes, or migrating to urban centers for seasonal employment.

Table 3
Natural Resources issues to adaptation and related Schemes.

Barrier	Issue for adaptation	How	Who	Schemes
Resource Barriers	Insufficient irrigation and water efficient infrastructure in rainfed areas	• Better irrigation management and innovative irrigation practices • Managed aquifer storage • Shift to improved irrigation methods (sprinkler, mini-sprinkler, trickle) • Reduce soil evaporation losses • Promoting sub surface irrigation (SDI) & restricted deficit irrigation (RDI) • Creation of stakeholders consortium	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare*, *Department of Agricultural Research and Education*), Ministry of Water Resources, River Development and Ganga Rejuvenation, Ministry of Rural Development (*Department of Rural Development*), Ministry of Environment, Forest and Climate Change, NABARD	• *Pradhan Mantri Krishi Sinchayee Yojana* • National Water Mission • National Innovations on Climate Resilient Agriculture • National River Conservation Plan • Mahatma Gandhi National Rural Employment Guarantee Scheme • Long term Irrigation fund and Micro-Irrigation Fund
	Soil degradation, soil erosion, waterlogging, salinization	• Managing soil erosion, strip/contour farming, crop rotation • Combating desertification& soil erosion • Organic sources to improve soil fertility, mulching • Judicious use of chemical pesticides for reducing pesticides residues • Biological control and IPM • Regular surveillance and monitoring	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare*)	• National Project on Management of Soil Health and Fertility • Soil Health Card • Mission on Plant Protection and Plant Quarantine • *Rashtriya Krishi Vikas Yojana*

Note: Adopted and modified from Singh et al. (2017), (2018a).

Table 4
Economic Barriers to adaptation and related schemes.

Constraints	Issue for adaptation	How	Who	Schemes
Credit and insurance constraints	● Inadequate provision and reach of formal financial credit and insurance facilities ● Financial illiteracy among poor farmers	● Credit and Insurance linkage ● Access to banking facilities ● Financial inclusion ● Risk insurance; direct risk transfer ● Premium subsidy ● Coverage of post-harvest losses ● Timely conduct of crop cutting experiments ● Increasing participation of farmer groups ● Satellite enabled risk assessment	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare*), Ministry of Finance, NABARD	● Interest Subvention Scheme for Short Term Crop Loans ● Kisan Credit Card Scheme ● *Pradhan Mantri Jan Dhan Yojana* ● *Pradhan Mantri Fasal Bima Yojana*
Market access and infrastructural Constraints	● Inefficiencies in the conduct of agriculture market and its access to farmers ● Lack of post–harvest and storage facilities ● Limited public procurement centers, and located at far off places ● Slow progress on all-weather road, electricity and internet connectivity in rural areas	● Market support measures ● Improving Investment agricultural infrastructure ● Convergence of govt. programs into umbrella schemes ● Setting up of warehouses, cold storage and cold chains ● Increased extension services ● Setting up of commodity and region wise clusters for farmers groups (FPOs) for marketing & storage ● Participation in commodity futures market	Ministry of Agriculture and Farmers Welfare (*Department of Agriculture, Cooperation & Farmers Welfare*), Ministry of Rural Development (*Department of Rural Development*), Ministry of Food Processing, Ministry of Food and Public Distribution	● Integrated Scheme for Agriculture Marketing ● E-National Agriculture Market Scheme ● Price Stabilization Scheme ● Agri-Tech Infrastructure Fund ● Mission for Integrated Development of Horticulture ● Mega Food Parks ● *Pradhan Mantri Gram Sadak Yojana* ● *Indira Awas Yojana* ● *Deen Dayal Upadhyaya Gram Jyoti Yojana*
Lesser off-farm livelihood options	● Insufficient off farm employment opportunities ● Under developed human capital (education) to absorb in other non-farm enterprises	● Linkage between farm and non-farm activities (Upstream & downstream) ● Incentivising rural non-farm activities ● Diversification-both vertical and horizontal ● Promotion of equipment, training and market facilities ● Enhancing gender and youth participation ● Skill development ● Promotion of livestock, dairy and fisheries sector	Ministry of Rural Development (*Department of Rural Development*), Ministry of Micro, Small and Medium Enterprises, Ministry of Skill Development, Ministry of Agriculture and Farmers Welfare (*Department of Animal Husbandry, Dairying & Fisheries*)	● Mahatma Gandhi National Rural Employment Guarantee Scheme ● National Rural Livelihood Mission ● *Pradhan Mantri Kaushal VikasYojana* ● Prime Minister's Employment Generation Programme ● Dairy Entrepreneurship Development Scheme ● National Dairy Plan

Note: Adopted and modified from Singh et al. (2017), (2018a).

mechanisms adopted by the farmers and the barriers preventing households from autonomous adaptations. The review necessitates the need for integrating adaptation and micro-level assessment to understand factors across different agro-climatic regions in order to develop suitable solutions that fit the local geographical context. Several programmatic interventions exist in the current rural development framework of the government that can help achieve the twin objective of adaptation and development, provided it effectively captures regional climatic considerations. Building capacity of community-based group, NGOs, cooperatives and farmers associations can create awareness on climate adaptation and technologies for sustainable livelihoods. Moreover, there is a need to strengthen private sector participation in development of post-harvest management, infrastructure building and climate research and development in the country. Strong institutional mechanisms need to be enforced to monitor, evaluate and address climate related technical and knowledge gaps for successful implementation of region specific climate change action plans. Moreover, participation and concerted efforts are needed to strengthen synergy between vertical and horizontal policy chain to effectively mainstream climatic consideration within the planning framework. The current scenario makes an urgent call for the policy maker and other stakeholders to review programmes and schemes for enhancing the adaptive capacity of vulnerable section and making Indian agriculture climate resilient. Similar initiatives can be replicated in other developing countries of the world having preponderance of agrarian economy and climate change threats.

Conflict of interest

None declared.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crm.2019.04.003.

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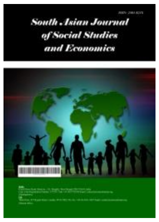

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Agriculture Development in India: A State Level Analysis

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Agriculture plays vital role in the process of economic development of less developed countries like, India. Besides providing food for the nation, agriculture absorbs labor, provides saving, contributes to the market of industrial goods and earn overseas exchange. The present study attempted to examine the performance of Indian agriculture during post green revolution period and economic reform period. A semi-log model was used to calculate compound annual growth rate of major food and non-food crops. Descriptive statistics were used to examine the land use pattern change and cropping pattern change. Fertilizer use ratio was calculated to examine the judicious use of chemical fertilizers. Study findings reveal that though, green revolution moved out from the food crisis arisen in the early sixties in some extent, but it also brought regional disparities in the resources use, productivity and cropping pattern. Promotional price policy for some cash crops leads to scarcity in others. Change in an environmental factors, along with economic and technological factors are increasing degree of the vulnerability in farm profits in particular and the livelihood of farmers in general. The present study suggested following policy implications. First, there is need of ultramodern technology that provides up-to-date weather information. Second, government should promote home-made bio-fertilizers and organic farm practices. Third, an intensive survey should be carrying out to understand the farm requirement of marginal farmers and based on the feedback mechanism, technology would be develop. Fourth, private investors should be invited to develop a food chain

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mechanism to procure the food items at the time of harvesting and release in the off-cropping season for price stability. Lastly, India needs land reforms, in which, land consolidation and identification of real farmers should be given first priority.

Keywords: Regional imbalances; CAGR; agriculture development; cropping pattern change; fertilizers consumption.

1. INTRODUCTION

Agriculture plays vital role in the process of economic development of less developed countries like, India. Besides providing food for the nation, agriculture absorbs labor, provides saving, contributes to the market of industrial goods and earn overseas exchange [1]. In India, agriculture has the main source of national income and occupation since independence [2]. During the first decade of independence, agriculture and allied activities contributed about 51.81 percent to India's national income and around 73 percent of the total working population were engaged in agriculture and allied sector. However, the share of agriculture to national income substantially has declined from 51.81 percent in 1951 to 18.20 percent in 2013-14 [2]. In spite of this, agriculture still has prominently playing vital role in the India's economic growth. Agriculture provides row materials for industrial sector and creates employment opportunities in the ever-growing service sector.

Since independence, Indian agriculture has been significantly progressing; it grew at the rate of one percent per annum for sixty years during pre-independence era 1860-1920. Further, it springs up at the rate of about 2.6 percent per annum in the post- independence era 1951-56 [1]. An increase in total cropped area was the main source of agriculture growth from fifties to eighties [2]. During mid-eighties, a structural change in the production was observed. Area was moderately declined, while per hectare production was increased substantially due to technological transformation. Apart from technological transformation, land reforms, an introduction of agricultural price commission with the objective to ensure remunerative prices to producers, new agricultural strategies, viz., introduction of hybrid seeds, chemical fertilizers, new cultivation & harvesting tools, improved irrigation facilities, agriculture credit & insurance, investment in research and extension services and improvement of rural infrastructure were taking place.

All these developments in Indian agriculture are contributed by a series of actions taken by the Indian government during mid-sixties. However, things are not always gone in the right direction. The dark side of agricultural development is that, it has increased disparity among the operational land holders, increases water scarcity & depletion, and increases water logging & salinity. The agricultural investment statistics also show deceleration trends in economic reform period during 1999-2012. Furthermore, natural calamities, higher interest rates, an increase in the wage rates, increase in prices of fertilizers, seeds & pesticides and lower minimum support price have increased degree of vulnerability in marginal and small farmers (i.e., about 86 percent).

With these evidences, the present study aimed to answer the following questions; (i) how a change in total cropped area and total net irrigated area has contributed into nation's food security, (ii) how land use pattern provided opportunities to increase agricultural production, (iii) how Green Revolution disproportionately affected the production of main food and non-food crops, (iv) Is an Indian agriculture sustainable occupation for marginal and small farmers, (v) Are Indian farmers judiciously using chemical fertilizers and (vi) how climatic factors are influencing the agriculture production and are responsible for agriculture production variability and creating seasonal food insecurity).

2. MATERIALS AND METHODS

2.1 Semi-log Model

The present study estimated the growth rate of food grains and non-food grains at national level and net sown area, gross sown area, consumption of fertilizers, number of tractors during post- Green Revolution period (PGRP) of 1966-90 and Economic Reform Period (ERP) 1991-2012 at the national and state level by using semi-log quadratic regression model, as follows.

$$Y_t = Y_0(1 + r)^t \qquad (1)$$

Where r is the compound (i.e., over time) rate of growth of Y. taking the natural logarithm of equation 1, we can write

$$\ln Y_t = \log Y_0 + t \ln(1 + r) \quad (2)$$

Now letting

$$B_1 = \ln Y_0 \quad (3)$$

$$B_2 = \ln(1 + r) \quad (4)$$

We can write equation (2) as

$$\ln Y_t = \beta_1 + \beta_2 T \quad (5)$$

Adding this disturbance term to equation (5), we obtain

$$\ln Y_t = \beta_1 + \beta_2 T + U_t \quad (6)$$

Model looks like, equation 6 is called semi-log model because only one variable (in the case of regressand) appears in the logarithmic form Gujarati [3].

3. RESULTS AND DISCUSSION

3.1 Land Use Pattern Change

Table 1 shows the trends of land use pattern change in India over a post-Green Revolution period. The present study has calculated the percentage change in area to total reporting area under the eight sub-categories of land use classification, viz., forest area, area not available for cultivation, permanent posture and grazing land, land under miscellaneous, culturable waste land, fellow land, current fellow and net sown area for the periods, viz., 1966-70, 1971-80, 1981-90, 1991-2000 and 2001-12. The results show that forest cover marginally increased about two percent during 1966-2012 at the cost of area not available for cultivation, permanent pasture and grazing land, land under miscellaneous and culturable waste. Further, net sown area is relatively associated with agricultural practices, shows marginally increased by about 1.22 percent during 1966-2012 respectively. Furthermore, an area more than once shows positive outcome of Green Revolution. Table 1 also indicates that area more than once use for cultivation increased about two percent during 1966-1990 and continuous increased by about six percent during 1991-2012.

3.2 CAGR of NSA, GSA, NIA and GIA: A State-level Analysis

It is noted that after policy reforms in agriculture (Green Revolution), total cropped area was increased at the national-level. The estimated compound annual growth rate (CAGR) shows that gross sown area (GSA) has marginally increased about 0.24 percent annually during 1991-2012 (Table 2). Nevertheless, net sown area (NSA) has declined by about 0.09 percent during the same period. CAGR of irrigation sources (both surface and ground water) net irrigated area (NIA) and gross irrigated area (GIA) show a marginal increased by about 1.26 and 1.55 percent during 1991-2012 at national-level. Disparity in CAGR of NSA, GSA, NIA and GIA has observed at the state level. Among the states, NSA has increased in Gujarat by 0.39 percent during 1991-2012. On the other hand, states like, Bihar, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh, Madhya Pradesh and West Bengal NSA has declined by about 2.35, 0.38, 0.16, 0.47, 0.25, 11.50, 0.89, 0.30, 1.96 and 0.26 percent. However, GSA shows lower declined trends in CAGR. It has declined in the Bihar, Himachal Pradesh, Kerala, Orissa, Tamil Nadu and Madhya Pradesh by about 2, 0.18, 0.58, 1.62, 1.20 and 1.18 percent in one hand and on the other hand, it has increased in Gujarat, Haryana, Jammu and Kashmir, Karnataka, Maharashtra, Punjab, Rajasthan and West Bengal by about 0.53, 0.62, 0.34, 0.28, 0.43, 0.23, 0.23 and 0.55 percent during respectively. The regional disparities have also observed in NIA and GIA at state level. Bihar is only the state, which shows a decline in a CAGR of NIA. In Bihar, NIA was declined by about 0.41 percent. On the other hand, remaining states NIA show increased in CAGR during the same period. It has increased in Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Punjab, Rajasthan, Uttar Pradesh, Madhya Pradesh and West Bengal by about 2.55, 0.69, 2.22, 1.04, 1.17, 0.34, 1.99, 1.07, 1.43 and 2.83 percent during. Moreover, the CAGR of GIA also shows regional variations. GIA was increased in Andhra Pradesh, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Maharashtra, Punjab, Rajasthan, Uttar Pradesh, Madhya Pradesh and West Bengal by about 0.96, 0.35, 2.94, 1.39, 0.46, 0.40, 1.99, 1.84, 0.43, 2.17, 1.22, 1.42 and 4.63 percent.

Possibly there are three main reasons responsible for the positive CAGR of GSA. First, increase in NIA and GIA due to agricultural subsidy in irrigation. State governments of Uttar Pradesh, Punjab, Haryana, Karnataka, Maharashtra and Madhya Pradesh had provided free cost of surface water through canal irrigation.

Table 1. Trends in land use pattern in India

Period	1966-70	1971-80	1981-90	1966-90	1991-00	2001-12	1999-2012
Forest	20.82	21.72	22.01	21.52	22.51	22.86	22.69
Area Not Available for Cultivation	15.57	13.63	13.32	14.17	13.40	13.89	13.65
Permanent Posture & Grazing land	4.51	4.15	3.88	4.18	3.62	4.43	3.52
Land under Misc.	1.34	1.29	1.18	1.27	1.22	1.12	1.17
Culturable Waste Land	5.35	5.68	5.19	5.41	4.69	4.36	4.52
Fellow land	3.01	3.01	3.26	3.09	3.27	3.34	3.31
Current Fellow	4.26	4.42	4.98	4.55	4.60	4.97	4.79
Net Sown Area	45.14	46.12	46.17	45.81	46.70	46.03	46.36
More than once	7.13	9.19	11.89	9.40	14.82	16.34	15.58

Source: Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note: values are percentage

Table 2. Compound annual growth of NSA, GSA, NIA and GIA during 1991-2012

State	Net sown area	Gross sown area	Net irrigated area	Gross irrigated area
Andhra Pradesh	-0.08^{NS}	0.15^{NS}	0.48^{NS}	0.96*
	(-0.56)	(0.86)	(1.63)	(2.73)
Bihar	-2.35*	-2.00*	-0.41**	0.35**
	(-9.12)	(-8.68)	(-2.10)	(2.13)
Gujarat	0.39*	0.53*	2.55*	2.94*
	(6.01)	(4.03)	(11.41)	(11.06)
Haryana	0.003^{NS}	0.62*	0.69*	1.39*
	(0.08)	(8.38)	(8.10)	(16.45)
Himachal Pradesh	-0.38*	-0.18*	0.35^{NS}	0.46*
	(-13.15)	(-5.40)	(1.63)	(8.03)
Jammu & Kashmir	0.04^{NS}	0.0034*	-0.02^{NS}	0.40*
	(1.47)	(8.35)	(-0.15)	(6.41)
Karnataka	-0.16***	0.28**	2.22*	1.99*
	(-1.78)	(2.15)	(11.06)	(7.24)
Kerala	-0.47*	-0.58*	1.04*	0.69*
	(-9.56)	(-5.65)	(10.24)	(2.83)
Maharashtra	-0.25*	0.43*	1.17*	1.84*
	(-7.37)	(6.15)	(5.42)	(11.50)
Orissa	-11.5*	-1.62*	-0.63^{NS}	-0.22^{NS}
	(-7.37)	(-3.50)	(-0.86)	(-0.30)
Punjab	-0.03^{NS}	0.23*	0.34**	0.43*
	(-1.11)	(5.33)	(2.41)	(8.37)
Rajasthan	0.24^{NS}	0.84**	1.99*	2.17*
	(0.65)	(1.97)	(6.35)	(6.64)
Tamil Nadu	-0.89*	-1.20*	0.30^{NS}	-0.18^{NS}
	(-5.62)	(-5.98)	(0.92)	(-0.51)
Uttar Pradesh	-0.30*	-0.07^{NS}	1.07*	1.22*
	(-6.27)	(-1.31)	(10.63)	(12.42)
Madhya Pradesh	-1.96*	-1.18*	1.43*	1.42*
	(-6.76)	(-3.17)	(2.77)	(2.68)
West Bengal	-0.26*	0.55*	2.83*	4.63*
	(-4.29)	(4.78)	(5.96)	(6.11)
India	-0.09***	0.24*	1.26*	1.55*
	(-1.75)	(3.05)	(13.55)	(12.93

*Source: Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4], Note Parenthesis value are t-statistics, *, ** & *** indicates one, five & ten percent level of significance and NS indicates non- significant*

Second, increase in rural electrification, promoted to use ground water with subsidized electricity or very nominal charges in the absence of strict environmental law. Lastly, price support policy for high irrigational crops like, wheat, rice and sugarcane had motivated to the farmers, especially small and marginal farmers to grow these crops [5].

3.3 Cropping Pattern Change

Table 3 depicts land use pattern change. It was observed that policy maker had diverted the resources in favor of main food crops (wheat and rice) and non-food crop (sugarcane) to insure food security in India. During 1966-70, the food grain and non-food grain crops shared the total cropped area by about 81.52 and 18.48 percent, while it has been changed during 2001-2012 by about 75.21 and 24.79 percent (Table 3). It is shifted in favor of non-food grain crops. Regional disparities in the expansion of total cropped area under food grain and non-food crops also observed. The total cropped area under food grain crops has increased substantially in the states viz., Bihar, Orissa, Punjab, Rajasthan, Uttar Pradesh and West Bengal by about 3.33, 3.98, 2.20, 0.82, 1.06 and 0.36 percent during 1966-2012, whereas it has marginally increased in Haryana, Jammu & Kashmir and Karnataka by about 0.55, 0.14 and 0.7 percent (Table 4). On the other hand, it has declined substantially in Andhra Pradesh, Gujarat, Madhya Pradesh and Tamil Nadu by about 1.86, 0.82, 3.93 and 1.58 percent, while, it has marginally declined in Kerala and Maharashtra by about 0.40 and 0.73 percent during the same period.

Similarly, the total cropped area under non-food grain crops substantially has increased in Madhya Pradesh, Rajasthan, West Bengal and Andhra Pradesh by about 7.83, 6.11, 6.26, 6.26 and 0.98 percent, while it has marginally increased in Haryana, Himachal Pradesh, Jammu and Kashmir, Kerala and Maharashtra by about 0.85, 0.27, 0.65 and 0.09 percent during 1966-2012 (Table 5). On the other hand, it has substantially declined in Uttar Pradesh, Tamil Nadu, Punjab and Karnataka by about 15.54, 3.61, 2.36 and 1.87 percent. Further, it has marginally declined in Bihar, Gujarat and Orissa by about 0.96, 0.99 and 0.52 percent.

Moreover, rapid shift in the cropping pattern in favor of food grain crops during 1966 to till mid-eighties has observed. After that, shift in the cropping pattern in favor of non-food grain crops observed up to 2012 (Table 3). State level disparities in the shift of food to non-food crops and non-food to food crops have reflection of national-level. There are four major reasons for these disparities at national as well as state-level. First, farmers have adopted new agricultural technology, such as hybrid seeds, chemical fertilizers and mechanical tools etc. disproportionately. Second, farmers have lower and disproportionate access of irrigation. Since the starting years of Green Revolution, coverage of irrigation has increased the cropped area of irrigation intensive crops such as rice, wheat and sugarcane, while area under less irrigation intensive crops substantially declined during post-Green Revolution period. Third, average land size in the states like, Uttar Pradesh, Haryana, Punjab, Madhya Pradesh, Karnataka and Rajasthan has a higher average land size compare to national level and farmers belonging to these states substantially contributed in the national food stock. Lastly, agricultural subsidy has decisive role in the agriculture production. So-called high yield producing states also have received higher share of the agricultural subsidy during post-Green Revolution period.

3.4 Performance of India Agriculture

The performance of Indian agriculture has been broadly categorized into three periods, viz., pre-Green Revolution during 1951-65, post-Green Revolution during 1966-90 and Economic Reform Period during 1991 to 2012. The present study estimates the growth pattern of area and production in two periods, viz., post-Green Revolution Period (PGRP) and Economic Reform Period (ERP) by using state as well as national-level data.[1] CAGR of food grain and non-food grain crops has increased by about 0.60 and 0.95 percent during PGRP (Table 6). CARG of major food grain crops, viz., rice and wheat shows that it has increased by 0.61 and 2.06 percent annually. Further, the CAGR of area of major non-food grain crops viz., sugarcane and total oilseeds has increased by 1.61 and 1.40 percent annually. However, the CAGR of area under cotton crop has declined by 0.27 percent annually.

During ERP, CAGR of area under food and non-food grain crops shows a marginal decline by 0.44 and 0.61 percent annually. CAGR of food

[1] Due to non- availability of state level data of most of food grain and non-food grain crops during 1951-65, the present study restricted during 1966 to 2012 period.

grain crops show a marginal increase in area under wheat sugarcane, total oilseeds and cottons by 0.83, 1.32, 0.22 and 1.52 percent.

Table 3. Shift in cropped area from food to non-food crops

Decade	Food grains	Non-food grains	Total
1966-70	120177 (81.52)	27244 (18.48)	147421 (100.00)
1971-80	124814 (81.53)	28274 (18.47)	153089 (100.00)
1981-90	131573 (80.86)	31143 (19.14)	162717 (100.00)
1991-00	130615 (77.09)	38820 (22.91)	169434 (100.00)
2001-12	122182 (75.21)	40272 (24.79)	162454 (100.00)

Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note: values are in '000' hectares, while parenthesis values are in percentage

Table 4. Selected state wise total cropped area under food grains

State	1966-70	1971-80	1981-90	1990-2000	2001-12
Andhra Pradesh	9233 (7.68)	9223 (7.39)	8752 (6.65)	7807 (5.98)	7112 (5.82)
Bihar	9597 (7.99)	9922 (7.95)	9741 (7.40)	9404 (7.20)	13827 (11.32)
Gujarat	4879 (4.06)	6783 (5.43)	7609 (5.78)	4229 (3.24)	3961 (3.24)
Haryana	3657 (3.04)	3995 (3.20)	3982 (3.03)	4068 (3.11)	4392 (3.59)
Himachal Pradesh	791 (0.66)	820 (0.66)	876 (0.67)	858 (0.66)	806 (0.66)
Jammu & Kashmir	776 (0.65)	806 (0.65)	875 (0.67)	907 (0.69)	908 (0.74)
Karnataka	7334 (6.10)	6974 (5.59)	7296 (5.55)	7633 (5.84)	7535 (6.17)
Kerala	908 (0.76)	902 (0.72)	742 (0.56)	509 (0.39)	280 (0.23)
Madhya Pradesh	16114 (13.41)	17227 (13.80)	18643 (14.17)	18848 (14.43)	12064 (9.87)
Maharashtra	13205 (10.99)	13361 (10.70)	14776 (11.23)	14566 (11.15)	12535 (10.26)
Orissa	5412 (4.50)	6203 (4.97)	7422 (5.64)	6389 (4.89)	10358 (8.48)
Punjab	3594 (2.99)	4268 (3.42)	5288 (4.02)	5888 (4.51)	6344 (5.19)
Rajasthan	11601 (9.65)	12393 (9.93)	12795 (9.72)	13570 (10.39)	12793 (10.47)
Tamil Nadu	5023 (4.18)	5076 (4.07)	4540 (3.45)	4023 (3.08)	3176 (2.60)
Uttar Pradesh	19154 (15.94)	19306 (15.47)	20819 (15.82)	21210 (16.24)	20763 (16.99)
West Bengal	5811 (4.84)	6329 (5.07)	6216 (4.72)	6639 (5.08)	6347 (5.20)
India	120177 (100.00)	124814 (100.00)	131573 (100.00)	130615 (100.00)	122182 (100.00)

Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note: values are in '000' hectares, while parenthesis values are in percentage

Table 5. Selected state wise total cropped area under non-food grains

State	1966-70	1971-80	1981-90	1991-00	2001-12
Andhra Pradesh	2416 (8.87)	2498 (8.84)	3073 (9.87)	4182 (10.77)	3966 (9.85)
Bihar	541 (1.99)	575 (2.03)	526 (1.69)	470 (1.21)	414 (1.03)
Gujarat	3778 (13.870	3839 (13.58)	3846 (12.35)	4339 (11.18)	5187 (12.88)
Haryana	531 (1.95)	582 (2.06)	813 (2.61)	1253 (3.23)	1128 (2.80)
Himachal Pradesh	25 (0.09)	26 (0.09)	24 (0.80)	78 (0.20)	144 (0.36)
Jammu & Kashmir	44 (0.16)	46 (0.16)	63 (0.13)	73 (0.42)	68 (0.81)
Karnataka	2251 (8.26)	2433 (8.61)	2841 (9.12)	3372 (8.69)	2573 (6.39)
Kerala	40 (0.15)	45 (0.16)	39 (0.13)	165 (0.42)	327 (0.81)
Madhya Pradesh	2597 (9.53)	2731 (9.66)	3250 (10.43)	5890 (15.17)	6991 (17.36)
Maharashtra	4705 (17.27)	4461 (15.78)	5287 (16.98)	5862 (15.10)	6627 (17.360
Orissa	402 (1.47)	600 (2.12)	1099 (3.53)	659 (1.70)	384 (0.95)
Punjab	903 (3.31)	952 (3.37)	928 (2.98)	901 (1.70)	621 (0.95)
Rajasthan	1538 (5.65)	1702 (6.02)	2402 (7.71)	4423 (11.39)	4734 (11.76)
Tamil Nadu	1498 (5.50)	1614 (5.71)	1553 (4.99)	1570 (4.05)	761 (1.89)
Uttar Pradesh	5067 (18.60)	5253 (18.58)	4131 (13.26)	2802 (7.22)	1231 (3.06)
West Bengal	647 (2.37)	704 (2.49)	960 (3.08)	1900 (4.90)	3474 (8.63)
India	27244 (100.00)	28274 (100.00)	31143 (100.00)	38820 (100.00)	40272 (100.00)

Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note: values are in '000' hectares, while parenthesis values are in percentage

CAGR of production of food and non-food crops show a marginal increase by 1.26 and 1.65 percent in the ERP. At crop level, CAGR of production of major food crops, viz., rice and wheat shows that it has increased by 2.90 and 5.30 percent. Further, CAGR of production of major non-food grain crops, viz., cotton, sugarcane and total oilseeds shows that it has increased by 2.50, 3.09 and 3.28 percent annually. CAGR of production of major food grain crops, viz., rice and wheat has increased by 1.34 and 1.91 percent, respectively. CAGR of production of major non-food grain crops, viz., cotton, sugarcane and total oilseeds also shows that it has increased by 5.29, 1.40 and 1.98 percent annually (Table 6). Similar CAGR of food grain and non-food grain crops in total has found. It has increased, but decreasing rate.

3.5 Determinants of Agriculture Production

The performance of Indian agriculture depends on numerous factors viz., economic, technological and environmental factors. Economic factors are most important for agricultural production, such as size of operational land holding. Technological factors, such as use of machinery (tractors), use of chemical fertilizers and pesticides are employed. Environmental factors, such as rainfall and temperature are used. The present study in this section investigates the change in use of the various factors at state as well as all India level during post green revolution and economic reform period.

Table 6. Compound annual growth rate of area and production during PGRP and ERP

Crop	PGRP		ERP	
	Area	Production	Area	Production
Rice	0.61*	2.90*	0.09[NS]	1.34*
	(9.20)	(11.70)	(0.86)	(5.85)
Wheat	2.06*	5.30*	0.83*	1.91*
	(9.69)	(16.38)	(7.08)	(8.67)
Cotton	-0.27*	2.50*	1.52*	5.59*
	(-1.94)	(6.98)	(4.65)	(6.19)
Sugarcane	1.61*	3.09*	1.32*	1.40*
	(7.63)	(11.70)	(4.59)	(3.61)
Total Oilseed	1.40*	3.28*	0.22*	1.98*
	(9.19)	(8.73)	(0.85)	(3.81)
Total Food grains	0.60*	2.93*	-0.44*	1.26*
	(8.33)	(14.54)	(-3.41)	(6.40)
Total Non-food grains	0.95*	3.02*	0.61*	1.65*
	(8.66)	(13.27)	(3.07)	(4.75)

*Source: Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note Parenthesis value are t-statistics, *, ** & *** indicates one, five & ten percent level of significance and NS indicates non- significant*

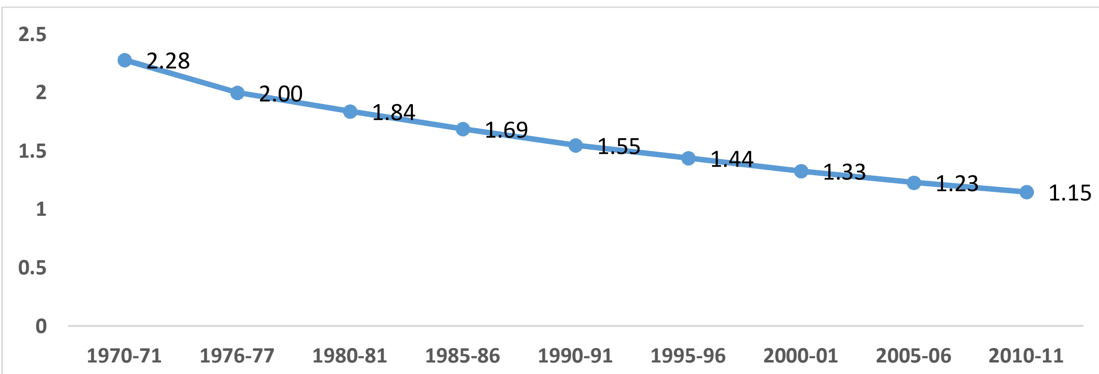

Fig. 1. All India average operation land holding size

Source: Department of Agriculture, Cooperation & Farmers Welfare, Government of India, [4]
Note: Values are in hectares

3.5.1 Economic factors

As an economic factors, the composition of operational land holdings across classes and social communities plays an important role for agricultural output. India is highly diverse nature in agricultural operations. Since majority of agricultural operational holders are marginal and small with regional difference, their numbers have increased in the subsequent years [4]. Fig. 1 shows declined in an average operation land holding size since 1970-71 to 2010-11. The average land size has substantially declined from 2.28 hectares in 1970-71 to 1.15 hectares in 2010-11. There are four possible reasons responsible for decline of land size. First, population growth has much higher. India has second most populous country in the world after China and it is continuously increasing [6]. Second, urbanization in India is in the fastest developing in the macrocosm. Consequently, new shelters and infrastructures require land for enlargement. Therefore, average farm size of land is now limiting year to year. Third, non-farm sector provides opportunities to semi-skill farmers. In the recent year, it is observed that non-farm sector growth is higher compared with farm sector with low risk and higher employment opportunities in all calendar months. Therefore, farmers those are having a small plot of land (landless small and marginal farmers) are shifting their primary occupation towards non-farm sector. Lastly, high input cost and lower returns with higher uncertainty. Other words, Indian agriculture become input intensive. It has increased the extra burden on the vulnerable marginal and small farmers.

Table 7. Number and area under class wise operational land holdings in India

Period	Marginal	Small	Semi-medium	Medium	Large
Distribution of operational land holdings					
1970–71	51.0	18.9	15.0	11.2	3.9
1980–81	56.4	18.1	14.0	9.1	2.4
1990–91	59.4	18.8	13.1	7.1	1.6
2000–01	62.9	18.9	11.7	5.5	1.0
2005–06	64.8	18.5	10.9	4.9	0.8
2010–11	67.0	17.9	10.0	4.3	0.7
Distribution of operational area					
1970–71	9.0	11.9	18.5	29.7	30.9
1980–81	12.0	14.1	21.2	29.6	23.0
1990–91	15.0	17.4	23.2	27.0	17.3
2000–01	18.7	20.2	24.0	24.0	13.2
2005–06	20.2	20.9	23.9	23.1	11.8
2010–11	22.2	22.1	23.6	21.2	10.9

Source: Department of Agriculture, Cooperation & Farmers Welfare, Government of India, [4]. Note: values are in percentage

Table 8. Selected state wise average operational land holdings

State	1995-96	2005-06	2010-11
Andhra Pradesh	1.36	1.20	1.08
Bihar	0.75	0.43	0.39
Gujarat	2.62	2.20	2.11
Haryana	2.13	2.24	2.25
Himachal Pradesh	1.16	1.04	0.99
Jammu and Kashmir	0.76	0.67	0.62
Karnataka	1.95	1.63	1.55
Kerala	0.27	0.23	0.22
Madhya Pradesh	2.28	2.02	1.78
Maharashtra	1.87	1.46	1.45
Odisha	1.30	1.15	1.04
Punjab	3.79	3.95	3.77
Rajasthan	3.96	3.38	3.07
Tamil Nadu	0.91	0.83	0.80
Uttar Pradesh	0.86	0.80	0.75
West Bengal	0.85	0.79	0.77
India	1.44	1.23	1.15

Source: Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture, Government of India, [4]. Note: values are in hectares

Additionally, agricultural census data from 1970-71 to 2010-11 shows that marginalization in has increased. Marginal farmers were 51 percent in 1970-71; they have increased by 17 percent, i.e., 67 percent in 2010-11 at the cost of large & medium farmers. The large farmer share was declined from 3.9 percent in 1970-71 to 0.7 percent in 2010-11. Subsequently, operated area has shifted from large farmers towards marginal and small farm holders. In 1970-71, 51 percent marginal farmers were owned 9 percent total cropped area. It has increased about 22 percent in 2010-11. On the other hand, 20 percent declined in the large farmer's total operated area during 1970-71 to 2010-11 (Table 7).

3.5.2 Regional shift in average land size

State wise shift in the average land size reflects that states having better institutional support such as water resources, investment and non-farm employment opportunities have higher average land size in the states, viz., Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab and Rajasthan, whereas Andhra Pradesh, Bihar, Himachal Pradesh, Jammu and Kashmir, Kerala, Odisha, Tamil Nadu, Uttar Pradesh and West Bengal compare to all country level (Table 8). High yield food crops producing states, viz., Punjab Haryana, Tamil Nadu and Kerala show marginal decline in the average land size across three agricultural census periods. On the other hand, states like, Bihar, Madhya Pradesh, Odisha and Rajasthan have shown sharp decline. It is a serious issue for policy point of view that when average land size is declining in one hand and on the other hand, demand of food items increasing. Will it be trapped with food insecurity? The current food crisis would be different from previous food crisis raised in the early fifties. In the fifties we were not fully used our natural, institutional and technological resources. Therefore, by using modern technology and expansion in the total cropped area, we sustain nation's food demand. But now we are at optimum level of agricultural operation and technically unable to increase total cropped area. Third, majority of farmers are own less than two hectare of land with high degree of vulnerability. Fourth, lack of political willingness in the development of agricultural sector also constrain of agricultural development.

The number of marginal farmers sharply has increased in backward states like, Bihar. In Bihar, marginal farmers were 80.14 percent in 1995-96 and it has increased by about 11 percent in 2010-11 (Table 9). Subsequently, states like, Uttar Pradesh and West Bengal the marginal farmers were 75.42 and 76.42 percent in 1995-96. They have increased to 79.23 and 82.17 in 2010-11. It was relatively much higher from national- level. The lower marginal owners from all India level are in Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Odisha, Punjab and Rajasthan. Among these states, Andhra Pradesh, Maharashtra, Madhya Pradesh and Punjab are high yield states. In other words, the rate of marginalization in the high yield states is lower and on the other hand, the rate of marginalization was higher in low yield states have observed.

From the farm output point of view, it is important that these marginal shareholders are not a real contributor in the national account statistics. They are, in other words called consumer rather than producers. An increase in the family size and decline land size put pressure of food insecurity. Therefore, they grow in majority food crops like, rice and wheat for own consumption rather than the profit motive.

3.5.3 Technological factors

Technological factors are also equally important and responsible for farm productivity. This section discusses about the performance of technological factors including consumption of chemical fertilizers and use of tractors during post green revolution period and economic reform periods.

Table 9. Selected state wise number and area under marginal operational land holdings

State	1995–96		2005–06		2010–11	
	Number	Area	Number	Area	Number	Area
Andhra Pradesh	59.42	20.20	61.58	22.69	63.95	26.08
Bihar	80.14	36.24	89.64	53.00	91.06	57.44
Gujarat	27.35	5.67	34.01	7.71	36.89	8.59
Haryana	47.16	10.99	47.66	9.66	48.11	9.87
Himachal Pradesh	64.43	23.00	68.27	26.65	69.72	28.48
Jammu & Kashmir	77.92	39.68	81.49	43.99	83.30	46.48
Karnataka	41.95	10.31	48.23	13.33	49.14	15.22
Kerala	93.95	53.27	95.63	57.62	96.33	58.64
Madhya Pradesh	40.38	8.20	40.45	9.92	43.86	12.09
Maharashtra	40.05	10.50	44.60	14.00	48.97	16.06
Odisha	54.08	20.68	59.62	26.74	72.17	39.53
Punjab	18.66	2.94	13.45	2.09	15.57	2.55
Rajasthan	30.03	3.67	33.51	4.85	36.47	5.86
Tamil Nadu	74.28	30.26	76.02	33.50	77.19	35.33
Uttar Pradesh	75.42	33.74	77.95	38.94	79.23	39.27
West Bengal	76.42	42.93	81.16	50.65	82.17	52.48
All-India	61.58	17.21	64.77	20.23	67.04	22.25

Source: Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture, Government of India, [4]. Note: values are in percentage

3.5.3.1 Chemical fertilizers consumption and agricultural productivity

By using chemical fertilizers during the PGRP, India sustains domestic food grains demand. The role of chemical fertilizers is important in the growth of Indian agriculture, as the net area available for cultivation is shrinking, due to the rising demand for land to build new houses, infrastructure and commercial outlets. In fact, the entire increase in farm output in the future may have to come from a rise in productivity. This will require improved technology and increased application of yield-enhancing plant nutrients. Therefore, a growth in fertilizer consumption is of paramount importance to raise food and agriculture production to meet the future requirements of the country. Among the core agendas of Green Revolution (use of hybrid seeds, improved irrigation and use of chemical fertilizers), use of chemical fertilizers was a second important agenda. Because hybrid seeds require chemical fertilizers to boost plant growth and total output. Therefore, after injection of fertilizer couple with high yielding varieties of rice and wheat since late 1960s, it has made possible to produce 15 to 20 tons of plant biomass (dry matter) per hectare per year. Therefore, farmers were started using of chemical fertilizer (especially nitrogen) at a massive level. Per hectare consumption of chemical fertilizer has increased four-fold during 1991-2012 from base year of 1965-66. It was 36 kilograms in 1965-66 and has increased 127 kilograms per hectare during 1991-2012 (Table 10). Regional disparities in the fertilizer consumption have also been taken place. States like Andhra Pradesh, Haryana and Punjab are most high fertilizer intensive states. In 1965-66 fertilizer consumption in these states was 41, 56 and 110 kilograms per hectare and it has increased by 180, 175 and 208 kilograms per hectare during 1991-2012. These states are using high yield varieties of rice, wheat and sugarcane, which need more fertilization coupled with improved irrigation. Andhra Pradesh has topped position for rice productivity per hectare. On the other hand, Odisha, Rajasthan, Madhya Pradesh, Kerala and Maharashtra are still using less. These states are using below 100 kilograms per hectare fertilizers. These regional variations show the scope for rising farm productivity by using fertilizer judiciously.

The judicious use of fertilizers not only make sustainable to farm practices, but also gives higher returns. The calculated CAGR shows positive growth in both two study periods, viz., PGRP and ERP in the nitrogen phosphate and potassium based fertilizer’s consumption. It was observed that CAGR of nitrogen based fertilizer was slowed in ERP compared with in PGRP. It was 9.22 percent in PGRP and remained 3.26 percent in ERP (Table 11). Similarly, CAGR of phosphorus and potassium based chemical fertilizers shows slowed in ERP compared with PGRP level. It was 10.22 and 4.24 percent in PGRP and remained 9.17 and 5.67 percent in ERP at national-level. Further, regional disparities in the consumption of chemical fertilizers have found. Among the states, Bihar, Haryana, Madhya Pradesh, Punjab, Uttar Pradesh and West Bengal reported more than 10 percent annual growth rate during the PGRP period (Table 11). However, in the ERP period, CAGR sharply has declined. Even though, the majority of states show a decline in the consumption of nitrogen, phosphorus and potassium except in Haryana, Punjab and Uttar Pradesh. In these states consumption of potassium based fertilizers has increased sharply in ERP compared with PGRP period. It was 9.36, 7.34 and 7.60 percent in PGRP period and it has increased by 17.84, 8.92 and 7.90 percent in the ERP period.

There are three possible reasons for decline in CAGR of fertilizer consumption. First, initially, farmers in the early 1960s have used fertilizers (especially nitrogen based) without consideration of plant requirements. When, fertilizer use reached a threshold-level or beyond the plant carrying capacity. It has negative consequences in output. Therefore, famers have shifted the use of fertilizers from nitro to potassium based fertilizers. In other words, farmers have now judiciously using fertilizers. Further, shift from nitrogen based fertilizers towards potassium based fertilizers was also observed in the higher food grains yield states, viz., Haryana, Punjab and Uttar Pradesh. Second, introduction of new bio-fertilizer and early maturing varieties in arid and semi-arid regions; a recent report published by the government of India shows that more than 60 percent cropped area under rain-fed conditions. It means water is not available for farming throughout the cropping seasons. Therefore, early maturing varieties and judicious use of chemical fertilizers are best option to cope with adverse climatic conditions. Lastly, supportive government price policy for nitrogen based fertilizers increased nitrogen based fertilizers consumption markedly during PGRP period.

Table 10. Fertilizers consumption in selected states during 1966 to 2012

State	1966-67	1966-90	1991-2012	∆ (change)
Andhra Pradesh	41	60	180	120
Bihar	39	46	121	75
Gujarat	26	35	109	74
Haryana	56	67	175	108
Karnataka	45	51	121	70
Kerala	31	44	71	28
Madhya Pradesh	11	18	65	47
Maharashtra	22	29	96	67
Orissa	0.5	9	43	33
Punjab	110	138	208	71
Rajasthan	7	11	42	31
Tamil	56	80	166	86
West Bengal	45	57	138	81
Uttar Pradesh	55	77	140	63
Jammu & Kashmir	24	79	184	105
Himachal Pradesh	12	67	169	102
India	36	54	127	72

Source: Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture, Government of India, [4]. Note: ∆ indicates change in Fertilizers Consumption during 1966-90 to 1991-2012. Values are in kilogram per hectare

3.5.3.2 Balance v/s imbalance use of chemical fertilizers

Since the introduction of chemical fertilizers in the Indian agriculture, the debate on the balanced use of fertilizer and its relation to plant growth was always a policy concern. In general, the Nitrogen, Phosphorus and Potassium (NPK) ratio of 4:2:1 is considered to be optimum for India. It is hard to trace the origin of this ratio [7]. However, it is believed that the ratio is originated from field trials conducted during the 1950s, i.e., in the PGRP [8]. The calculated NPK ratios show that states like Karnataka, Kerala, Maharashtra, Tamil Nadu and West Bengal have used lower from the recommended ratio of NPK during PGRP. They have used NPK ratio of 3:1:1, 1:1:1, 3:2:1, 3:1:1 and 4:1:1 (Table 12). Further, high yield states, viz., Haryana, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh have used much higher from the recommended ratio during PGRP. They have used NPK ratio of 32:7:1, 10:6:1, 19:7:1, 21:7:1 and 11:3:1. To maintain the high agricultural growth rate, these states have used more intensive chemical fertilization during the ERP period. During ERP period, farmers have not only increased the share of nitrogen based fertilizers but also increased the share of phosphorus and potassium based fertilizers (Table 12).

3.5.3.3 Growth in use of tractor

Traditionally, Indian farmers were used bulk for farm management before the introduction of tractor. Tractor has multi-purpose utility equipment. It is not only used in farming, but also used in the non-farm activities. It has labor cost cutting technology and helps to increase farm profits. Table 13 indicates that CAGR of tractors during 1966-90 and 1991-2012. It was observed that during 1966-90 that growth rate of tractor use in the agriculture were more than 10 percent in Andhra Pradesh, Bihar, Punjab, Haryana, Rajasthan and Uttar Pradesh. However, during 1991-2012 it has remained about 5 percent, except in Tamil Nadu.

3.5.4 Environmental factors

Temperature and rainfall are major environmental determinants, responsible for crop productivity in any piece of land. The distribution of rainfall and temperature is different and vary location to location. In the plains, it is higher and in hilly area, temperature generally remains lower. Due to this, the vegetation is also different like some crops are grown at lower temperature between 15- 21°C and at the same time, some crops grow with temperature between 20- 28°C [9]. Plant has a minimum threshold level. If temperature (day & night) increased beyond minimum threshold level, surely affects to the growth of the plant. Along with IPCC [9] on global temperature and its negative consequences on global environment as well as human's livelihood several mainstream researchers [10,11,12] observed that temperature (day & night) adversely affected to the crop productivity and declined net farm revenue.

3.5.4.1 Variations in the rainfall distribution pattern

Sinha and Swaminathan [10]; Goswami et al. [13] and Kumar et al. [14] observed that rainfall pattern has shifted from southern parts towards central plains. Means drier regions would be received less rainfall and wetter regions would be received higher rainfall in the coming years. It is confirmed that Gujarat, Karnataka, Maharashtra, Orissa and West Bengal have received surplus rainfall by 103, 43, 20, 93 and 63 millimeter, whereas Andhra Pradesh, Bihar, Haryana, Himachal Pradesh, Kerala, Madhya Pradesh, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh have received less rainfall by 16, 108, 36, 13, 9, 48, 66, 7, 19 and 155 millimeter in the monsoon period during 1966-90 to 1991-2012 (Table 14). Further, it was observed that due to climate variability, monsoon rainfall distribution pattern has changed. Regional variations in the monsoon period restricted farmers to change cropping pattern along with sowing period or else ready to accept less profit. Goswami et al. [13] observed that less precipitation available for high water intensive *khariff* crops due to change in

Table 11. State wise compound annual growth rate of chemical fertilizers (Nitrogen, phosphorus and potassium) consumption during PGRP and ERP

State	1966-90			1991-2012		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Andhra	8.62*	9.84*	16.42*	2.97*	4.62*	8.16*
Pradesh	15.41)	(17.68)	(8.52)	(8.26)	(9.80)	(13.98)
Bihar	10.40*	12.16*	12.40*	5.41*	7.05*	12.12*
	(22.63)	(11.40)	(14.29)	(5.12)	(4.64)	(7.46)
Gujarat	8.61*	9.83*	9.53*	4.67*	5.36*	7.66*
	(17.98)	(10.99)	(6.78)	(9.66)	(9.21)	(10.85)
Haryana	11.77*	17.70*	9.36*	3.67*	4.74*	17.84*
	(17.20)	(16.50)	(4.47)	(24.56)	(14.77)	(9.84)
Himachal	9.67*	6.07*	9.41*	1.49*	6.03*	7.17*
Pradesh	(17.79)	(7.79)	(5.72)	(7.66)	(7.36)	(9.05)
Karnataka	9.19*	11.59*	12.53*	4.07*	5.56*	6.14*
	(24.01)	(22.07)	(10.93)	(10.38)	(7.36)	(10.12)
Kerala	5.33*	5.62*	7.70*	2.54*	3.19*	2.10*
	(17.96)	(11.20)	(13.72)	(6.51)	(7.89)	(4.63)
Madhya	12.51*	14.71*	13.95*	3.10*	4.40*	6.30*
Pradesh	(16.55)	(17.58)	(15.71)	(4.09)	(6.46)	(6.52)
Maharashtra	9.06*	9.74*	13.57*	3.46*	6.21*	7.14*
	(9.69)	(14.96)	(5.88)	(9.69)	(12.26)	(9.99)
Orissa	8.70*	10.53*	12.40*	3.90*	7.61*	6.29*
	(15.06)	(21.11)	(18.46)	(9.69)	(14.89)	(10.15)
Punjab	10.58*	14.68*	7.34*	2.19*	2.87*	8.92*
	(15.70)	(12.41)	(3.22)	(15.37)	(8.39)	(12.19)
Rajasthan	9.20*	12.54*	8.11*	4.24*	5.43*	7.94*
	(19.39)	(19.76)	(6.27)	(17.65)	(10.53)	(8.85)
Tamil Nadu	6.18*	6.59*	8.58*	1.93*	3.12*	2.09*
	(11.85)	(11.43)	(17.16)	(8.93)	(6.44)	(3.60)
Uttar Pradesh	10.43*	11.14*	7.60*	2.51*	5.36*	7.90*
	(13.61)	(8.62)	(4.41)	(13.96)	(14.02)	(9.36)
West Bengal	12.27	16.03*	15.82*	2.51*	4.83*	6.15*
	(30.00)	(18.89)	(7.90)	(12.98)	(13.68)	(11.46)
India	9.22*	10.22*	9.17*	3.26*	4.24*	5.67*
	(23.58)	(18.92)	(15.63)	(15.19)	(9.73)	(8.44)

*Source: Source: Ministry of Agriculture and Farmers Welfare, Government of India, [4]. Note Parenthesis value are t-statistics, *, ** & *** indicates one, five & ten percent level of significance*

Table 12. Selected state wise consumption and ratio of nitrogen, phosphorus and potassium during PGRP and ERP

State	NPK Ratio (PGRP)	NPK Ratio (ERP)
Andhra Pradesh	9:3:1	5:2:1
Bihar	8:2:1	9:2:1
Gujarat	8:4:1	8:3:1
Haryana	32:7:1	42:13:1
Himachal Pradesh	7:1:1	4:1:1
Karnataka	3:1:1	3:2:1
Kerala	1:1:1	1:1:1
Madhya Pradesh	10:6:1	12:7:1
Maharashtra	3:2:1	3:2:1
Orissa	5:2:1	5:2:1
Punjab	19:7:1	32:9:1
Rajasthan	21:7:1	32:13:1
Tamil Nadu	3:1:1	2:1:1
Uttar Pradesh	11:3:1	17:5:1
West Bengal	4:1:1	2:1:1
India	7:2:1	6:2:1

Source: Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture, Government of India, [4]. Ratios has calculated by k = 1, for Potassium, N = N/K for Nitrogen and P = P/K for Phosphorus

Table 13. Selected state wise compound annual growth rate of number of tractors during PGRP and ERP

State	PGRP	ERP
Andhra Pradesh	10.79*	2.03*
	(49.09)	(6.74)
Bihar	12.84*	4.39*
	(35.93)	(9.22)
Gujarat	8.14*	5.14*
	(15.29)	(9.04)
Haryana	10.50*	0.39*
	(60.01)	(0.77)
Himachal Pradesh	-2.08*	05.84*
	(-0.93)	(10.39)
Karnataka	7.04*	1.53*
	(9.98)	(2.70)
Kerala	2.57*	8.63**
	(5.91)	(2.14)
Madhya Pradesh	15.66*	2.40*
	(15.52)	(4.29)
Orissa	3.23*	7.37*
	(5.30)	(8.26)
Punjab	12.30*	5.18*
	(-0.77)	(1.60)
Rajasthan	13.84*	4.02*
	(47.14)	(9.43)
Tamil Nadu	7.77*	10.49**
	(12.16)	(2.37)
Uttar Pradesh	13.03*	4.18*
	(46.77)	(11.15)
West Bengal	-7.11**	2.04*
	(-2.13)	(6.32)

*Source: Estimated from ICRISAT Database. Note: parenthesis value are t-statistics, *, ** & *** indicates one, five & ten percent level of significance*

Table 14. Change in annual and monsoon rainfall in selected states during PGRP and ERP

State	Annual rainfall PGRP			Monsoon rainfall ERP		
	1966-90	1991-2012	∆ (in M.M.)	1966-90	1991-2012	∆ (in M.M.)
Andhra Pradesh	978	962	-16	505	489	-16
Bihar	1221	1051	-170	779	671	-108
Gujarat	1536	1649	113	1228	1331	103
Haryana	603	581	-22	415	379	-36
Himachal Pradesh	1236	1182	-54	692	679	-13
Karnataka	1292	1363	71	770	813	43
Kerala	2575	2837	262	1620	1611	-9
Madhya Pradesh	1051	1017	-34	804	756	-48
Maharashtra	1234	1251	17	898	918	20
Orissa	1306	1457	151	835	928	93
Punjab	642	532	-110	419	353	-66
Rajasthan	582	569	-13	448	441	-7
Tamil Nadu	1025	1029	4	246	227	-19
Uttar Pradesh	979	747	-232	651	496	-155
West Bengal	1220	1308	88	716	779	63
India	1170	1169	1	835	825	-10

Source: Indian Meteorological Department of India, 2013. Note: for the estimation of State level rainfall distribution, geographical location of the meteorological stations has comprised. ∆ indicates change in rainfall distribution. Values are in millimeters

Table 15. Selected state wise change in mean minimum and maximum temperature during PGRP and ERP

State	PGRP		ERP	
	Minimum temperature	Minimum temperature	Maximum temperature	Maximum temperature
Andhra Pradesh	21.96	21.85	32.99	32.58
Bihar	19.62	19.44	27.67	27.50
Gujarat	19.76	19.93	26.70	26.85
Haryana	18.14	18.56	31.56	31.85
Himachal Pradesh	13.03	13.75	22.54	23.02
Karnataka	20.32	20.62	25.67	25.93
Madhya Pradesh	19.00	19.26	32.40	30.49
Maharashtra	20.23	20.41	27.75	27.91
Orissa	20.68	19.70	28.49	27.47
Punjab	17.86	18.37	28.65	29.01
Rajasthan	18.82	19.30	31.16	31.61
Tamil Nadu	22.48	22.91	21.63	21.94
Uttar Pradesh	18.78	19.23	32.17	32.51
West Bengal	20.29	20.81	31.00	31.05
India	19.36	19.58	28.60	28.55

Source: Indian Meteorological Department of India, 2013. Note: for the estimation of State level rainfall distribution, geographical location of the meteorological stations has comprised. Values are in degree centigrade

monsoon rainfall pattern [13]. They also observed that rainfall in early Rabi cropping season adversely affected to the Rabi crop, such as wheat. Further, the frequency of heavy and very heavy rain events in central India increased by nearly 50 percent and more than 100 percent during 1951-2000. All India annual rainfall distribution shows that regional variations not only in the monsoon period have increased but it also increased in the annual distribution.

3.5.4.2 Change in day and night temperature

Table 15 indicates the change in day and night temperature. It was observed that states like Gujarat, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Orissa and West Bengal shows that night (minimum) temperature has increased during 1966-90 to 1991-2012. On the other hand, night temperature in states like, Bihar, Rajasthan and Uttar Pradesh has declined during the same period. Further, day (maximum) temperature is important for the vegetative growth of the plants reflects regional variations. It has increased in the states, viz., Gujarat, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal during 1966-90 to 1991-2012, while it has declined in Andhra Pradesh and Bihar. Current findings are match from the Kaur and Kaur [15] study. By using simulation method, his study projected about wheat crop that in Northern India State such as Uttar Pradesh, Punjab, Haryana, Uttarkhand and Himachal Pradesh affected by increasing trends of temperature. Wheat output could plunge by 6 million tons with every 1°C rise in day temperature.

4. CONCLUSION AND POLICY RECOMMENDATION

The present study start begin question of performance of Indian agriculture, sustainable farm practices, food security and how well Indian farmers dealing with climate change. By using large-scale data at national and state-level, input-output analysis was carried out in two periods, viz., post- green revolution period and economic reform periods. The results show that production of food and non-food crops has tremendously increased over the period and nowadays India has surplus food stock to deal with any future food crisis. However, the dark side of the green revolution also observed. First, technological change in the mid-eighties caused significantly shift in land utilization in favor of food grain crops such as wheat and rice at the cost of the area under coarse cereals, pulses and oilseeds. This shift was combined effect of differential rate of technological change among the crops. Second, irrigation bias of new technology causing shift, of land away from dry crops in favor of irrigated crops and the associated policy price- support system as well as market intervention by the government for certain crops [16]. Third, distortions in cropping pattern were reflected in the relatively abundant supply of the same crops (like wheat of which government has surplus stock) and acute shortages of others (like pulses and oilseeds which had to be imported at the huge cost in terms of foreign exchange). Fourth, the input cost has increased many folds [17]. High yielding food grain technology along with fertilizer and irrigation needs more investment in agriculture. With least coverage of institutional credit sources, green revolution pushed in poverty and credit trap to the marginalized Indian farmers. Fifth, emphasis on the agricultural development policy (green revolution) was more on raising the yield of a particular crop per unit of land rather than increasing the total output per unit of land from all crops growth in a year [18]. Sixth, change in land use pattern. Sharma [19] examined the inter-state disparities in cropping pattern and agriculture growth. Study found that size of land holding has basic factor affecting the structure of cropping pattern across the states. The state with higher agricultural growth rates was having a relatively higher average size of holding except Uttar Pradesh, Punjab and Haryana. Lastly, shift from traditional to unsustainable farm practices. Das [20] argued that traditionally, Indian farmers were small plots of land protected by windbreaks and tree cover. The practices of crop rotation and leaving the field fallow for long periods of time allowed the soil to retain nutrients. However, farmers were then influenced by the green revolution and large farmer who had changed to modern method, such as mono-cropping, in which they cultivated only one type of crop rather than multiple crops, as is done in traditional farming. While mono-cropping allows farmers to grow more of a certain crop that usually of higher market value. It has negative effects on the soil as well. A farmer who applies a mono-cropping system tend to leave their fields fallow for a shorter period of time. Thus, the soil cannot replenish its nutrients. Moreover, farmers that employ mono-cropping methods need higher inputs such as chemical fertilizers, pesticides and improved irrigation facilities.

Though, from the early years of the green revolution period, farmers have adopted intensive chemical fertilization, which was much higher from the recommended ratio. But Chand and Pavithra [7] criticized that validity of this ideal ratio. They argued that this ratio ignored two important factors. First, during the green revolution period, farmers applied farm-yard manure (bio-fertilizers) and the native soil were rich in phosphorus and potassium content. Second, the response to applied phosphorus and potassium fertilizers was much higher in red and lateritic soils, which clearly indicate that the ratio of NPK would vary for different soil types. Further, the fertilizer norm for a state or country depends upon the cropping pattern, yield levels, crop variety and soil-specific characteristics which have undergone a sea change over the years. The farm trails conducted in the post-green revolution period confirmed that the response of rice crop to the applied phosphorus was as good as to that of nitrogen and in fact it was higher in the case of improved varieties of wheat. This finding along with the popularization of improved wheat varieties encouraged the use of Phosphate fertilizers during the post green revolution period [7]. However, use of fertilizer in India remained skewed towards Nitrogen based fertilizers. They suggested that the ideal ratio in India based on the current crop pattern and recommendations of SAUs and ICAR institutions were found to be 2.6:1.4:1. This norm implies that N should comprise 52 percent and P and K should constitute 28 and 20 percent, respectively, of the total fertilizer applied in India. These shares are quite different from the share based on the ratio of 4:2:1, which implies that N should constitute 57.8 percent, and P and K should constitute 28.6 & 14 Percent respectively [21].

COMPETING INTERESTS

Author has declared that no competing interests exist.

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