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TB-ICN: 136/2014

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Published by

Director
ICAR–Indian Agricultural Research Institute, New Delhi-110012

Year 2014

Correct Citation

Naresh Kumar S., S.K. Bandyopadhyay, R.N. Padaria, A.K. Singh, Md. Rashid, Md. Wasim, Anuja, Ranjeet Kaur, D.N Swaroopa Rani, B.B. Panda, L.M. Garnayak, Suresh Prasad, M. Khanna, R.N. Sahoo and V.V. Singh 2014. Climatic Risks and Strategizing Agricultural Adaptation in Climatically Challenged Regions. IARI, New Delhi Publication. TB-ICN: 136/2014, P 106.

TB-ICN: 136/2014

Published by the Centre for Environment Science and Climate Resilient Agriculture
ICAR-Indian Agricultural Research Institute, New Delhi 110012, India.

Printed at

Venus Printers and Publishers, B-62/8, Naraina Industrial Area, Phase-II, New Delhi 28, Ph.: 45576780, Mobile: 9810089097, Email: pawannanda@gmail.com

Foreword

Climatic change, variability and extreme events in recent past have emerged as potential threats to rural livelihoods. However, except for relief and some contingency measures, there had been lack of pragmatic strategy or model of planned interventions for sustainable livelihood security under climatic risks.

The team of scientists under World Bank-GEF funded project entitled 'Strategies to Enhance Adaptive Capacity to Climate Change In Vulnerable Regions' (in NAIP Comp 3: Climate Change Adaptation with ICAR Code 303601) emphasized upon delineating the climatic risks and devising adaptation strategy aiming at holistic development of farming community through proper integration of climatic risk analysis, resources, agricultural crops, village seed banks, community nursery, livestock, resource conservation practices, livelihood options, village resource and custom hiring centers, ICT mediated knowledge and advisory support system, farmers' groups and institutions, and market linkage.

The project work was carried out in consortia mode in which the partnering institutes played a pivotal role in attaining the objectives. The support and cooperation of the Directors/VC/Head of the Organizations of the consortia partners (CRRI, Cuttack; CMFRI, Mumbai; OUAT, Bhubaneswar; TCS- Innovation lab, Mumbai) as well as Joint Director (Research), Joint Director (Extension), and Head, IARI Regional Station Indore are highly appreciated. The efforts put by the project team lead by Dr. SK Bandyopadhyay, farmers and local coordinators is commendable.

I congratulate Dr S. Naresh Kumar and the team for bringing out this publication which has the comprehensive analysis of climatic risks in past, future climatic projections, bio-physical characterization, strategizing the adaptation options and their intervention results, and adaptation gains and costs. This publication may be used as an approach document for projects on adaptation to climate change.

(H.S. Gupta)
Director, IARI

Contents

Executive Summary

- Indian agriculture is projected to be influenced by the climate change impacts necessitating adaptation for developing resilient agricultural systems and rural livelihoods. Adaptation costs and gains may vary depending on the nature of agricultural system, and the size and character of farm.
- Under the NAIP project sponsored by World Bank-GEF, stress was laid upon the broad objectives of developing community based sustainable rural livelihood strategies to minimize adverse climatic impact on drought as well as flood prone vulnerable areas and enhancing adaptive capacity of the stakeholders. Project was implemented in over 50 villages in 2 drought prone districts (Mewat- Haryana; Dhar-Madhya Pradesh) and 2 flood prone districts (Ganjam-Orissa; Raigadh-Maharashtra).
- This project emphasized on 1) identification of current and future climatic risks, and risks to livelihoods due to climatic variability, 2) development of drought indices to facilitate Early Warning System for drought & promoting their use in adaptation by farmers and other stakeholders, 3) develop community based sustainable rural livelihood strategies to minimize adverse climatic impact on climatically vulnerable districts and 4) capacity building of the stakeholders on strategies for alternate livelihoods in future climates.
- Analysis of past climate indicated that these areas have been experiencing climatic stresses such as heat stress, droughts, rainfall variability and flood events. Future climate (based on a Regional Climate Model outputs) in these distracts is likely to be warmer, particularly during winter (*Rabi*) season. Seasonal mean minimum temperatures during monsoon (*Kharif*) are likely to increase in the range of 1.49 to 1.87 ^{o}C with higher increase in Dhar and Mewat districts. Mean seasonal minimum temperatures during winter season are projected to rise in the range of 2.16 to 2.73 ^{o}C. The mean seasonal maximum temperatures during monsoon season are projected to rise in the range of 1.35 to 1.69 ^{o}C while during winter the increase is projected in the range of 1.2 to 2.13 ^{o}C. The monsoon rainfall is projected to increase marginally in Mewat and Raigadh districts and substantially in Ganjam district, whereas, winter rainfall is projected to reduce in Dhar and Ganjam districts. On

the other hand no change in rabi rain fall is projected for Raigadh district. Apart from these mean changes, climatic variability is projected to increase.

- Simulation analysis of the impact of past as well as the projected climate scenarios on yield of major crops such as wheat, maize, rice, soybean and mustard using InfoCrop indicated crop yield loss without adaptation. Simple adaptation options such as change in variety (ex. short duration, heat tolerant), adjusting sowing time, and nutrient and irrigation management not only can offset the negative impacts but also increase yields substantially.
- Agriculture and livelihood related risks as well as the technological and skill gaps were identified.
- Based on the simulation analysis and following the participatory approach, an adaptation strategy was developed and systematic interventions were planned and implemented in about 5000 farmers' fields
- Multi-dimensional interventions were based on 1) crops and their management, 2) change in crop varieties, 3) crop diversification, 4) livestock and fodder management, 5) value addition, 6) developing/improving secondary skills, 7) improving the individual and community natural resource management 8) improving the line-department and local institutional linkage 9) improving awareness and 'know-how' on various aspects of agriculture 10) improving 'do-how' on crop and natural resource management 11) knowledge empowerment of the farmer through information, 12) set up of the village resource centers for knowledge and hard-ware support 13) establishing the seed villages 14) enhancing the horticultural and plantation activities and 15) development of human resource at village level for sustaining the intervention impacts.
- Appropriate technologies for adaptation were tested and demonstrated with farmers' participation and capacity building support was provided through trainings, extension literature and mKRISHI (mobile) based advisory services. The interventions in action plan majorly focused upon (a) promotion of water harvesting through community based interventions like bund-making, small check dam, deepening of bore wells, renovation of water harvesting structures, (b) promotion of efficient utilization of water through use of underground pipeline for water conveyance and irrigation with drip, sprinkler and rain gun systems, (c) introduction of superior crop varieties for high yield and tolerance to stresses. For instance early and terminal heat stress tolerant varieties of wheat, (d) crop diversification with vegetables for income enhancement and

for house hold nutritional security, (e) integration of Resource Conservation Technologies (RCTs), Integrated Pest Management (IPM) and Integrated Nutrient Management (INM) technologies, shade nets for raising quality vegetable nursery, (f) promotion of scientific livestock management practices to reduce calf mortality, improve health and nutrition, and enhance milk productivity, (g) use of ICT for information dissemination, (h) capacity building of farming community for not only minimizing the climatic risks but also to improve the overall income from agricultural activities through value addition of farm produce (dahlia, dhal, chilly, turmeric powder making), (i) additional income generation activities such as tailoring, apiary, mushroom cultivation, back yard poultry, etc. and (j) convergence of local line departments, financial institutions, service providers, research and developmental institutions (KVKs) and markets.

- The economic analysis of adaptation cost and adaptation gains indicates that the profit is not directly proportional to the cost of adaptation, if any, among different strata of farmers. Adaptation cost was not same across the strata. In general, small farmers had more adaptation cost (particularly those having <=2 acre) than the large farmers (>=4 acre). However, the small farmers realized higher adaptation profit/unit area. These farmers generally have the cereal-vegetable cropping system. Large farmers may have to rationalize their management investments for gaining more profits, while small farmers may have to face additional cost for adaptation to climate change. The farmers growing 3-4 grain crops could increase profits by replacing at least one grain crop with vegetable cultivation.
- This publication contains a brief description of climate analysis, climate change projections, development of simulation and participatory based adaptation strategy, implementation of adaptation technologies and their field performance in the broad areas of crops, livestock, water, secondary skill development, knowledge based extension and socio-economic components in enhancing farm and house hold income, and increasing resilience of farms and societies to climatic stresses and climate change.
- The comprehensive approach followed in this project viz., i) identification of current and future climatic risks, ii) risks to livelihoods due to climatic variability, iii) develop scientifically derived and community based sustainable rural livelihood strategies and their implementation to minimize adverse climatic impact on climatically vulnerable districts and iv) convergence and capacity building of

the stakeholders on strategies for resilient farm income and livelihood may be followed as a model for adaptation to climate change and up-scaled with appropriation to suit specific needs.

- The team sincerely acknowledge the invaluable contributions of the project scientists from the different centres in identifying, testing and disseminating the adaptation technologies for building the adaptive capacity of the farmers and societies. The team also appreciate and thank the project staff as well as the technical, administrative and supporting staff of IARI and other Institutes for their sincere and hard work in project implementation. Above all, sincere thanks to WB-GEF and ICAR-NAIP for funding this project.

Introduction

India has about 60% of population whose livelihood is directly dependent of agriculture. Climate is one of the major drivers of Indian agriculture, with monsoon playing the dominant role. A good monsoon year results in high agricultural production, particularly in rainfed areas. However, climate change is projected to significantly influence the monsoon rains and temperature regime with negative effects on crop production in most of the areas and crops. Increased anthropogenic activities led to rise in the concentration of greenhouse gases causing the global climate change. IPCC report (2013) indicates that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years. The report indicated an observed warming of approximately 0.6°C to 0.7°C over period 1951 to 2010. Out of this, the contribution from natural forcing is likely to be in the range of –0.1°C to 0.1°C, and from natural internal variability is likely to be in the range of –0.1°C to 0.1°C implying that 0.6 °C increased due to anthropogenic activities. The report further indicates that anthropogenic influences have affected the global water cycle since 1960 and contributed to observed increases in moisture content in the atmosphere, to changes in precipitation patterns over land and to intensification of heavy precipitation events.

Continued enhancement in the GHG emissions meant accelerated change in climate and its variability. The global climate models project an increase of global mean surface temperatures in the range of 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5) for 2081–2100 relative to 1986–2005 period. The projected increase in temperature for south Asia is in the range of 0.5 to 1.2 °C by 2020, 0.88 to 3.16 °C by 2050 and 1.56 to 5.44 °C by 2080, depending on the scenario of future development. Further, the projections indicate increase in frequency of droughts, floods, and extreme events of temperature and rainfall. These environmental changes are likely to increase the pressures on Indian agriculture.

The simulation modelling assessments projected a decrease in the yield of major crops such as wheat, rice, maize, sorghum, mustard, groundnut, soybean, cotton, potato and coconut in India (Aggarwal and Sinha 1993, Lal et al. 1998, Saseendran et al. 2000, Mall and Aggarwal 2002, Aggarwal and Mall 2002, Byzesh et al., 2010, Srivastava et al., 2010, Naresh Kumar, 2011, Naresh Kumar and Aggarwal, 2013; Naresh Kumar et al., 2011, Naresh Kumar et al., 2012, 2013, 2014) if no adaptation is followed. However, these studies also indicate that adaptation can improve the yields significantly.

Since climate change enhances the climatic risks to the crop growth and development, adaptation is the primary strategy to sustain the crop productivity and farm income. Adaptation can increase the yield in spite of climate change and enhances the net productivity in the range of 18-32% by 2050 in most of the crops (Naresh Kumar et al., 2012, 2013, 2014). As rural communities depend mainly on agriculture for livelihood, adaptation strategy should also address the on-farm and off-farm related activities apart from crop management. Further, inclusion of non-farm activities in an integrated adaptation strategy will enhance the livelihood security in general and resilience to climatic risks, in particular. Resilience is the stability and sustainability of the system even in the event of external shocks.

Considering the significance of the emerging challenges of climate change to livelihoods security, a project was envisaged. Knowledge based natural resource and agricultural management as well as the participatory adaptation strategy were the key approaches followed in this project. The project was aimed to build resilience into resource-based livelihoods in drought affected districts of Madhya Pradesh and Haryana and flood affected districts of Orissa and Maharashtra against climatic risks. For this, two drought prone districts (Mewat- Haryana and Dhar-Madhya Pradesh) and two flood prone districts (Ganjam- Odisa and Raigadh- Maharashtra) were selected with the objectives to

1. Identification of current and future risks to livelihoods due to climatic variability
2. Development of drought indices to facilitate Early Warning System (EWS) for Drought & promoting their use in adaptation by farmers and other stakeholders
3. Develop community based sustainable rural livelihood strategies to minimize adverse climatic impact on drought as well as flood prone vulnerable districts
4. Capacity building of the stakeholders on strategies for alternate livelihoods in future climates.

This project was funded by World Bank GEF from 2009 to 2014.

This bulletin summarizes the characterization of climatic risks, adaptation framework and selected success stories of the interventions. In order to successfully implement a meaningful adaptation strategy, it should be scientifically developed. For doing so, characterization of climatic stresses and risks becomes indispensable.

Characterization of Climatic Stresses and Risks in Four Districts

Climatic characterization of a region becomes important for planning, strategizing and implementing any developmental plan, more so when it involves agriculture. In this project, the climatic characterization is done for all four districts. Further, the projected climate change is also analyzed for the four selected districts.

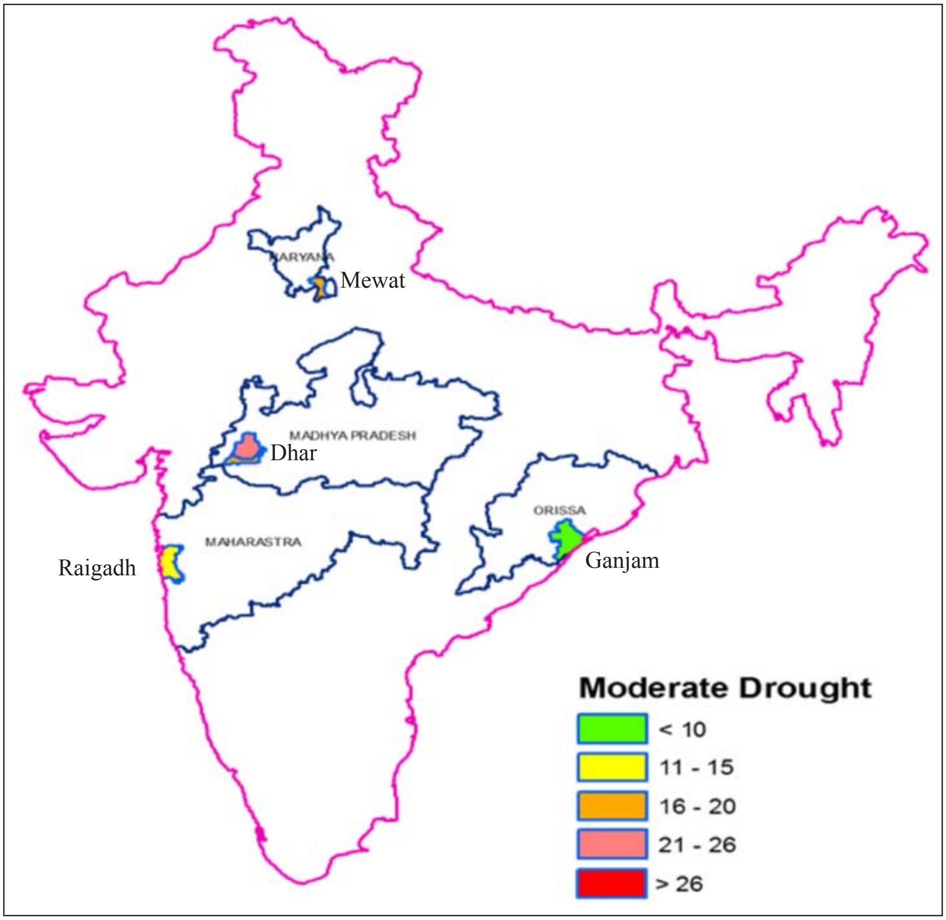


Fig. 1: Location of four districts selected for interventions on adaptation to climate change (India mainland map)

Study areas

Based on the Planning Commissions' list of climatically challenged districts, four districts viz., Mewat (Haryana), Dhar (Madhya Pradesh), Raigarh (Maharashtra) and Ganjam (Orissa) were selected (Fig 1). Geographically, two districts (Mewat and Dhar) fall in inland while other two fall in the coastal zone (Raigadh and Ganjam). The selected districts are located in north (Mewat) and central (Dhar) zones and in east (Ganjam) and west coast (Raigarh) of India.

Data and methods

Observed data

For climatic characterization, two types of data were used. 1) IMD daily gridded data from 1969-2005 and 2) block-wise daily rainfall data for past 30 years. Daily data were analyzed for deriving the summary statistics for climate of the region. The analysis included 1) mean and deviation from mean rainfall 2) change in rainfall intensity, rainfall pattern and number of rainy days 3) mean and change in temperature in the past.

Climate projections data

The data of a regional climate model PRECIS (Providing Regional Scenarios for Impact Studies, which had HadCM3, Hadley Centre Climate Model, as the global climate model) for 2030 (2010-2040) A1b scenario were used to derive projections for monthly and seasonal changes in temperature and rainfall. This scenario was found to be a near representative developmental pathway for Indian region (INCCA, 2011) and also was used for assessing the impacts of climate change on crop production in India's Second National Communication to UNFCCC (NATCOM, India, 2013). The A1b emission scenario represents a developmental pathway where future world will have very rapid economic growth; global population that peaks in mid-century and declines thereafter; rapid introduction of new and more efficient technologies; convergence among regions; capacity building and increased cultural and social interactions with a substantial reduction in regional differences in per capita income. The A1b scenarios is distinguished by balanced use of energy sources. The climate projection data included daily and monthly outputs on minimum and maximum temperatures, and rainfall.

Climate change scenarios were derived from the climate model projected changes in monthly temperatures (minimum and maximum) and rainfall. For this the delta method was used where change in temperature and rainfall were derived by subtracting the model derived baseline period (1960-1990) values from 2030 scenario data and then these change fields were appended to the IMD observed data as per the method explained in Naresh Kumar et al., 2011.

Table 1: Area, production and productivity of major crops in four districts

Crop	Season	Area (ha)	Production (Mg)	Yield (Mg/ha)
Mewat				
Wheat	Rabi	81464	302286	3.76
Mustard	Rabi	30612	43183	1.46
Pearl Millet	Kharif	25502	38286	1.50
Sorghum	Kharif	11827	4293	0.36
Rice	Kharif	7238	19000	2.64
Dhar				
Soybean	Kharif	249156	282550	1.13
Wheat	Rabi	143511	300429	1.98
Cotton	Kharif	98043	93685	0.94
Maize	Kharif	67406	97332	1.41
Chickpea	Rabi	46352	40902	0.81
Sorghum	Kharif	19700	13587	0.73
Black gram	Kharif	7971	2378	0.30
Green gram	Kharif	5601	1642	0.29
Pearl Millet	Kharif	5134	2224	0.44
Ganjam				
Rice	Kharif	269760	397010	1.45
Rice	Winter	265764	448576	1.68
Rice	Summer	77416	1591	1.28
Green gram	Kharif	47958	9288	0.19
Pigeon pea	Kharif	10430	7335	0.70
Black gram	Kharif	7740	1504	0.19
Finger millet	Kharif	5558	4743	0.85
Ground nut	Kharif	5127	5979	1.16
Raigadh				
Rice	Kharif	115265	279625	2.43
Rice	Summer	8411	21722	2.58
Finger millet	Kharif	10185	7914	0.77
Rabi pulses	Rabi	10206	4601	0.54

Source: Department of Agriculture and Cooperation

Brief description of the districts

Geographically and agriculturally, the selected districts vary but all of them have rural population with agriculture as the dominant source of income. These rural communities predominated with small and marginal farmers. As agriculture is the main livelihood source of these communities, the climatic characterization and risk analysis was done from agricultural point of view. These districts have wheat, soybean and rice as the major crops (Table 1). Several other crops such as pearl millet, sorghum, cotton, chickpea and green gram are also grown in substantial area. However, in most of the cases, productivity of these crops is significantly low as compared to the state and national average of respective crops.

Climatic characterization of the study areas

Climate of four districts

The climate of four districts was derived from 30 years daily data on rainfall, minimum and maximum temperatures, as these are the major factors that influence the crop growth and yield.

Mewat: Mewat district has the mean annual maximum and minimum temperatures of 31.7/17.3 °C. During the year, normal maximum temperatures were in the range of 21-41 °C and minimum temperatures were in the range of 5-27°C (Fig 2), with warm and dry summers and very cool winters. This district receives an average annual rainfall of ~583 mm mainly from the last week of June to mid-September.

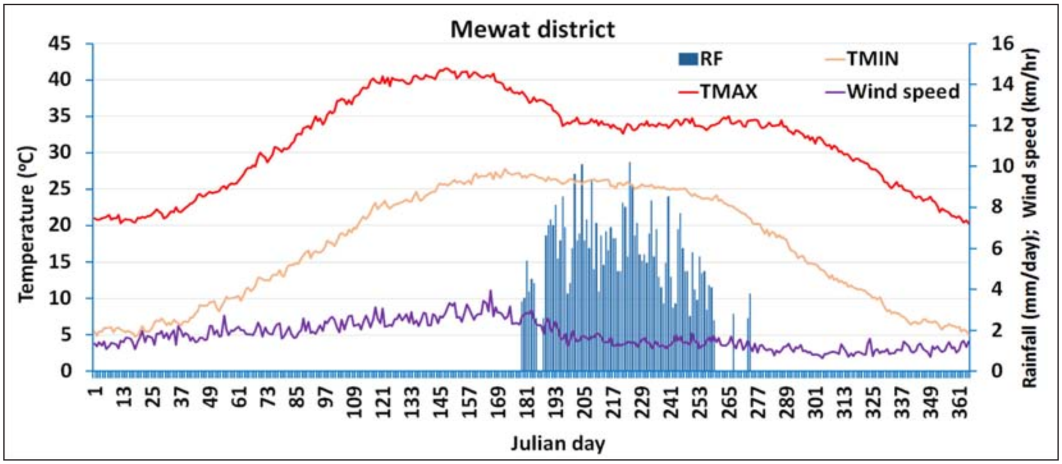


Fig. 2: Climatic conditions of Mewat district in terms of mean rainfall and temperatures.

Dhar: Dhar district has the mean annual maximum and minimum temperatures of 32.4/19.6 °C. During the year, normal maximum temperatures fall in the range of 27-39 °C and minimum temperatures fall in the range of 13-24°C (Fig 3), with warm and dry summers and cool winters. It receives an average annual rainfall of ~856 mm mainly during mid-June to mid-October period.

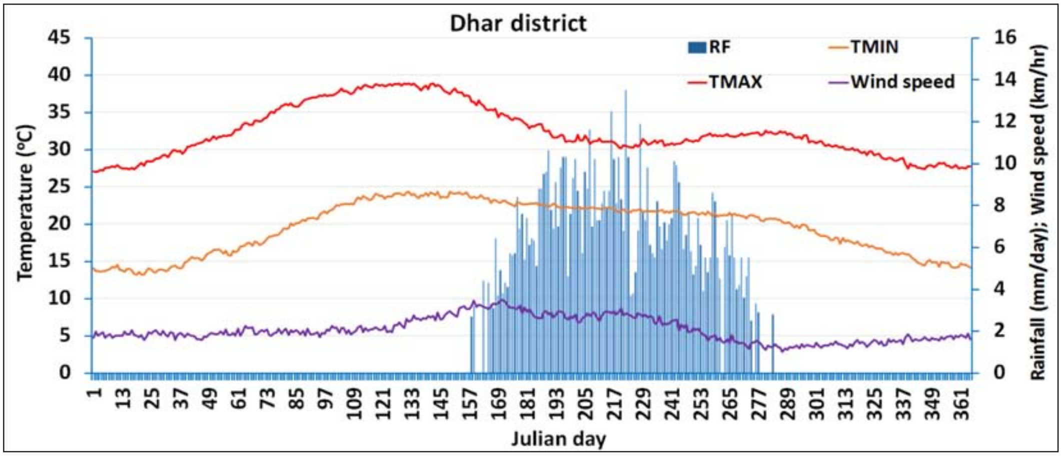


Fig. 3: Climatic conditions of Dhar district in terms of mean rainfall and temperatures.

Ganjam: Ganjam district has the mean annual maximum and minimum temperatures of 31.2/22.1 °C. During the year, normal maximum temperatures fall in the range of 27-36 °C and minimum temperatures fall in the range of 13-27 °C (Fig 4), with warm and

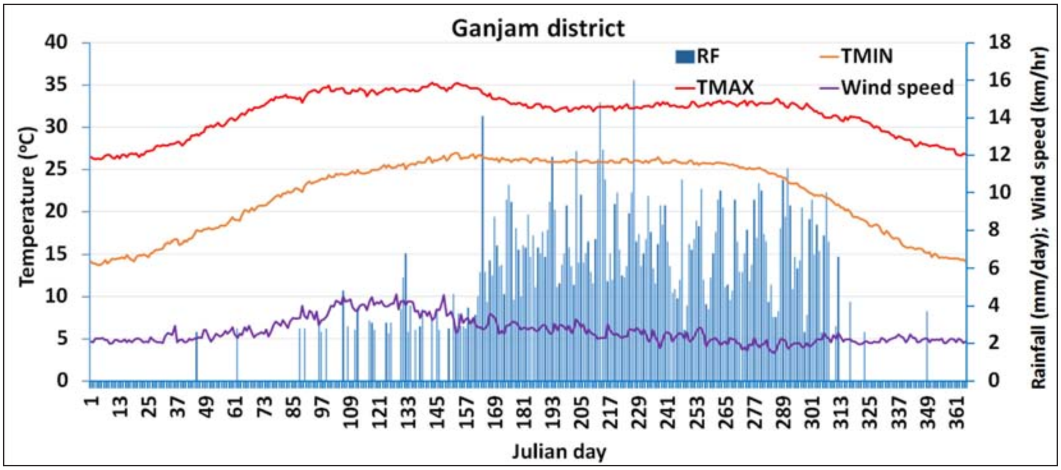


Fig. 4: Climatic conditions of Ganjam district in terms of mean rainfall and temperatures.

humid summers. The district receives an average annual rainfall of ~1358 mm mainly from last week of May to mid-November.

Raigadh: Raigadh district has the mean annual maximum and minimum temperatures of 31.0/20.4 °C. During the year, normal maximum temperatures fall in the range of 28-36 °C and minimum temperatures fall in the range of 15-24 °C (Fig 5), with warm and humid summers. It receives an average annual rainfall of ~3075 mm concentrated during the last week of May to October period.

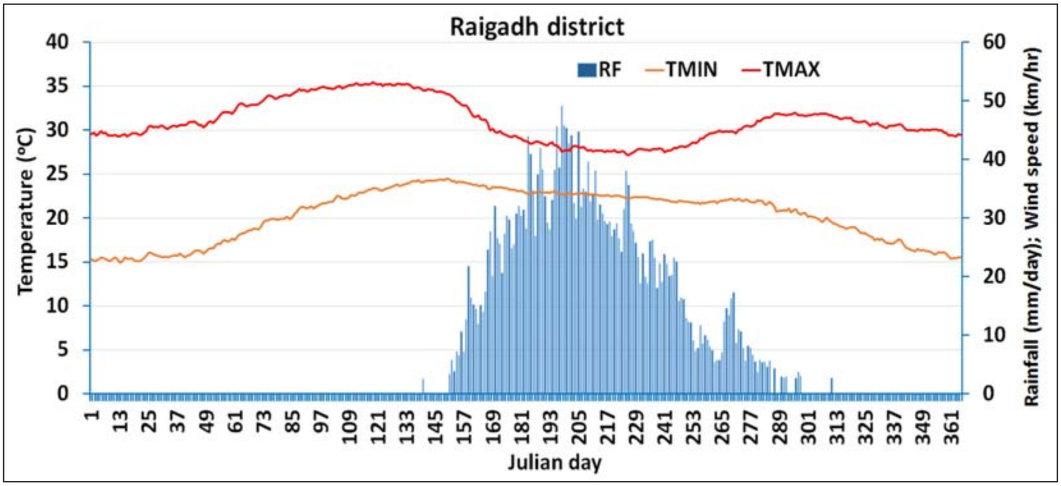


Fig. 5: Climatic conditions of Raigadh district in terms of mean rainfall and temperatures.

Analysis of past-climatic variability

Out of four selected districts, two (Mewat and Dhar) are prone to droughts while remaining two (Ganjam and Raigadh) are prone to floods. In past 100 years Mewat has experienced 18 moderate droughts and 8 severe droughts, while Dhar has experienced 21 moderate and 3 severe droughts. The flood prone district Ganjam had faced about 17 flood years since 1964 including Super cyclone in 1999 and Phylin in 2013. On the other hand Raygadh district faced occasional flood situation and also a severe flood in 2005. Both these districts also experienced 5 and 12 moderate droughts, respectively. Further, these districts also faced one severe drought each so far.

Mean change in climatic conditions

Analysis of past data from 1971 indicated a general increasing trend in maximum and minimum temperatures. During the monsoon (kharif) season, mean seasonal minimum temperatures increased at a rate of 0.18 and 0.07 °C in every 10 years in

Mewat and Dhar districts, respectively. In Raigad they increased at a rate of 0.04°C per 10 years. On the other hand in Ganjam the mean seasonal minimum temperatures have decreased at a rate of 0.1 °C in every 10 years period. However, during winter (rabi) season, mean seasonal minimum temperatures have increased in all four districts with higher increase in Mewat followed by Ganjam, Dhar and Raigadh. The mean seasonal maximum temperatures during kharif decreased marginally in Mewat and Ganjam districts while they have increased in Dhar and Raigadh districts. During rabi season, the mean seasonal maximum temperatures have increased substantially in Dhar, Ganjam and Raigad districts. The rate of increase has ranged from 0.13 to 0.26 °C for every 10 years period. Analysis on change in rainfall indicated that the rainfall has reduced by 1% and 19% in past 36 years period (1969-2005) in Mewat and Dhar districts, respectively. Since these two regions (particularly Mewat) are low rainfall zones, any reduction in rainfall has severe bearing on the agricultural activities. The rabi season rains, even though are very scarce, have increased over a period of time in Mewat, but in Dhar they are have decreased. In Ganjam, rainfall has increased during both the seasons, while in Raigadh the kharif season rains increased while rabi season rains decreased.

Inter-annual variability in seasonal weather

Analysis of past data from 1971 indicated a significant inter-annual variability for monsoon and winter season temperatures as well as for rainfall. This was quantified separately for monsoon and winter season. Seasonal anomaly indicated the deviation in mean seasonal maximum and minimum temperatures from respective long term means. This also served as an indicator of inter-annual variation. Coefficient of variation was computed to quantify the intra-seasonal as well as inter-annual variation.

Monsoon season

Mewat: The seasonal mean maximum temperature anomaly has ranged from about -1.5 °C to about 3°C over monsoon seasonal mean since 1971 in Mewat (Fig 6a). The coefficient of variation ranged between 5 and 12.5%. On the other hand, the seasonal mean minimum temperature anomaly has ranged from ~ -0.6 °C to ~1.2 °C over monsoon seasonal mean since 1971 (Fig 6b). However, coefficient of variation ranged between 14 and 18%. Post year 2000, mean minimum temperatures during monsoon season have been consistently higher than long term mean indicating warming in this region.

Dhar: The seasonal mean maximum temperature anomaly has ranged from ~ -1.5 °C to ~2°C over monsoon seasonal mean since 1971 in Dhar (Fig 7a). The coefficient of

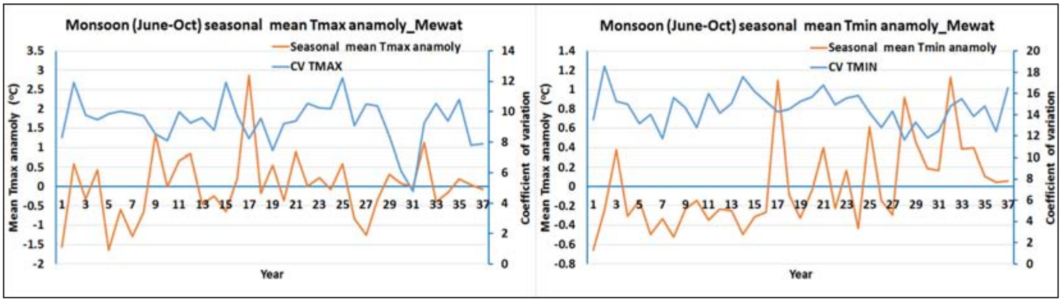


Fig. 6: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during monsoon in Mewat district. Intra-seasonal variability is indicated by the coefficient of variation.

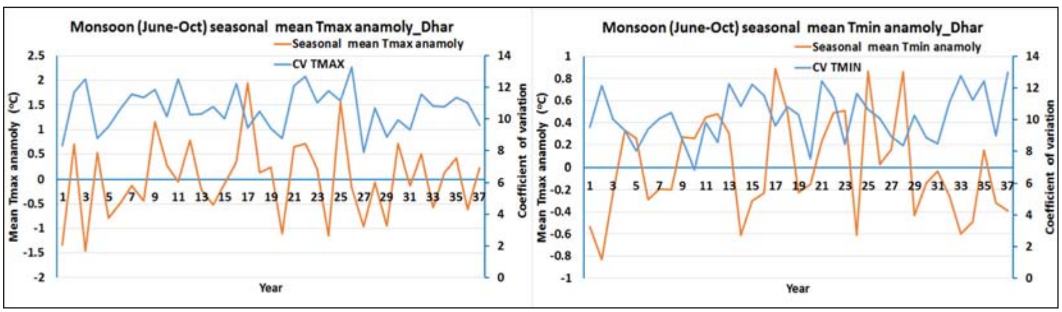


Fig. 7: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during monsoon in Dhar district. Intra-seasonal variability is indicated by the coefficient of variation.

variation ranged between 8 and 14%. On the other hand, the seasonal mean minimum temperature anomaly has ranged from ~ -0.8 °C to ~0.85 °C over monsoon seasonal mean since 1971 (Fig 7b). The coefficient of variation ranged between 7 and 13%. Generally, seasonal mean temperatures were lower during post 2000 year than the long term mean.

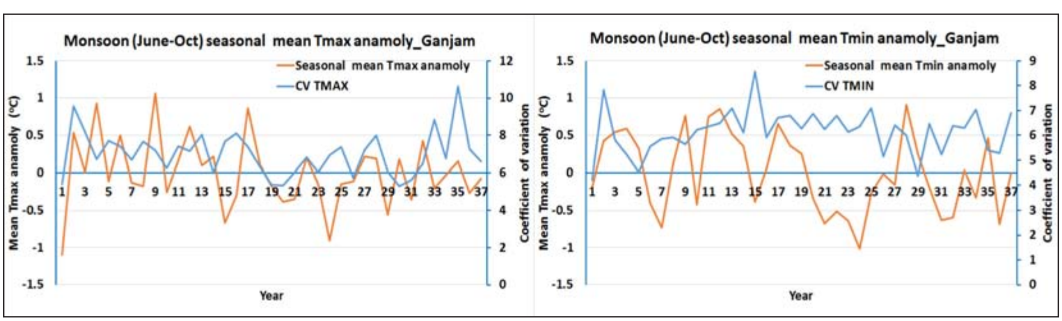


Fig. 8: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during monsoon in Ganjam district. Intra-seasonal variability is indicated by the coefficient of variation.

Ganjam: In Ganjam, the seasonal mean maximum temperature anomaly has ranged from ~ -1.1 °C to ~1.1°C over monsoon seasonal mean since 1971 (Fig 8a). The coefficient of variation ranged between 5 and 10.5%. The seasonal mean minimum temperature anomaly has ranged from ~ -1 °C to ~1 °C over monsoon seasonal mean since 1971 (Fig 8b). The coefficinet of variation has ranged between 4 and 13%.

Raigadh: The seasonal mean maximum temperature anomaly has ranged from ~ -0.8 °C to ~1.1°C over long term monsoon seasonal mean since 1971 in Raigadh (Fig 9a). The coefficinet of variation ranged between 6 and 9%. On the other hand, the seasonal mean minimum temperature anomaly has ranged from ~ -0.8 °C to ~0.6 °C over the long term mean for the corresponding period (Fig 9b). The coefficinet of variation has ranged between 4 and 7.5%.

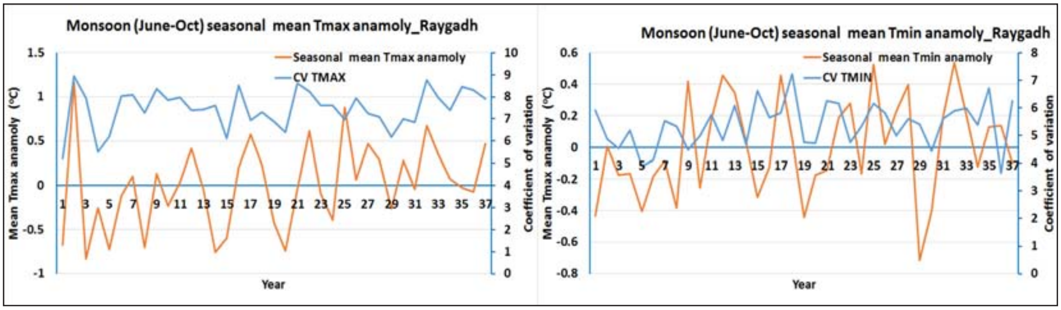


Fig. 9: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during monsoon in Raigadh district. Intra-seasonal variability is indicated by the coefficient of variation.

Winter season

Mewat: Though seasonal mean maximum temperature anomaly during winter ranged from-2.5 to 1.2 °C since 1971, most of the years had higher seasonal mean maximum temperatures than long term mean (Fig 10a). A cople of years were very cool. The

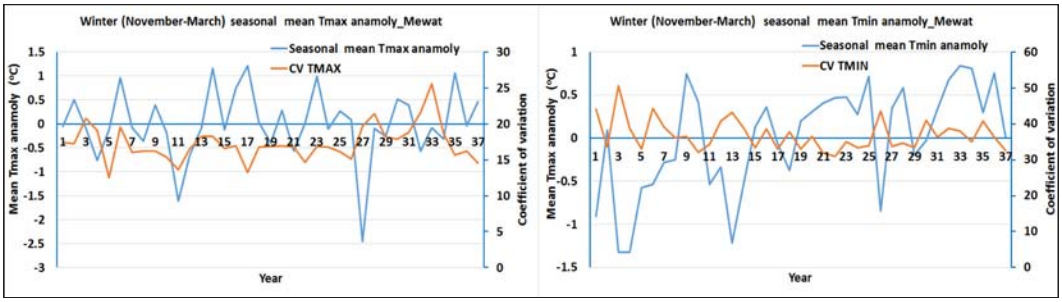


Fig. 10: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during winter season in Mewat district. Intra-seasonal variability is indicated by the coefficient of variation.

coefficient of variation ranged from 13 to 25%. On the other hand, seasonal mean minimum temperatures deviated in the range of -1.4 to 0.8 °C. Past one decade had more incidences of lower temperatures as compared to the long term seasonal mean minimum temperature (Fig 10b). The coefficient of variation is also very high ranging between 32 and 52%.

Dhar: In Dhar, seasonal mean maximum temperature anomaly during winter ranged from-1.5 to 1.2 °C. Most of the years had higher seasonal mean maximum temperature than the long term mean (Fig 11a). The coefficient of variation ranged from 9 to 14%. On the other hand, seasonal mean minimum temperatures deviated in the range of -1.6 to 1.5 °C (Fig 11b). The coefficient of variation for seasonal mean minimum temperatures has been high falling between 20 and 32%. This also showed a gradual declining trend.

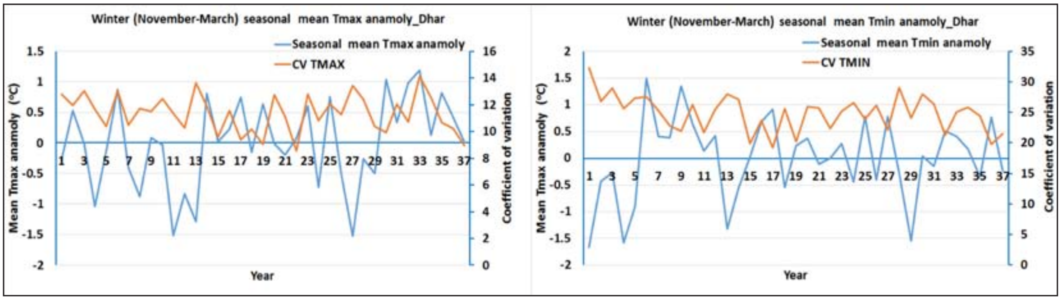


Fig. 11: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during winter season in Dhar district. Intra-seasonal variability is indicated by the coefficient of variation.

Ganjam: In Ganjam, seasonal mean maximum temperature anomaly during winter ranged from -1 to 1°C, most of the years in past one decade had higher seasonal mean maximum temperature than the long-term mean (Fig 12a). The coefficient of variation ranged from 4 to 12%. Seasonal mean minimum temperatures deviated in the range of -1.5 to 1.7 °C (Fig 12b). The coefficient of variation for seasonal mean minimum temperatures has been high, ranging between 13 and 24%. In contrast to maximum temperature, seasonal mean minimum temperatures were lower than the long-term mean during past one decade.

Raigadh: Seasonal mean maximum temperature anomaly during winter ranged from -1 to 1.2°C. Most of the years in past one decade had higher seasonal mean maximum temperatures than the long-term mean (Fig 13a). The coefficient of variation ranged from 3 to 8%. On the other hand, seasonal mean minimum temperatures deviated in the range of -1.3 and 1.5 °C from long-term mean (Fig 13b). The coefficient of variation for seasonal mean minimum temperatures ranged between 9 and 16%.

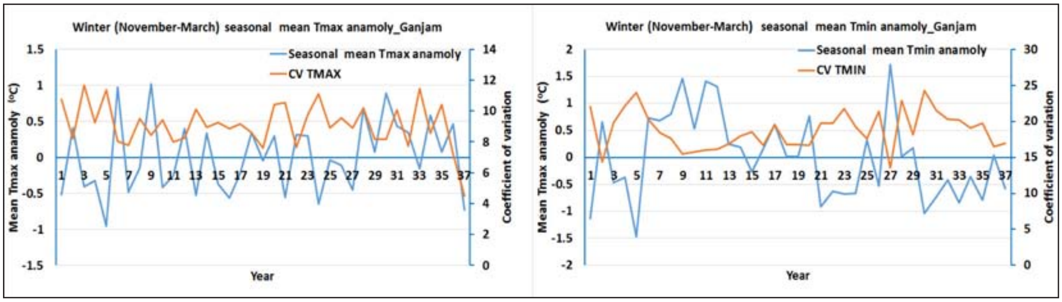


Fig. 12: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during winter season in Ganjam district. Intra-seasonal variability is indicated by the coefficient of variation.

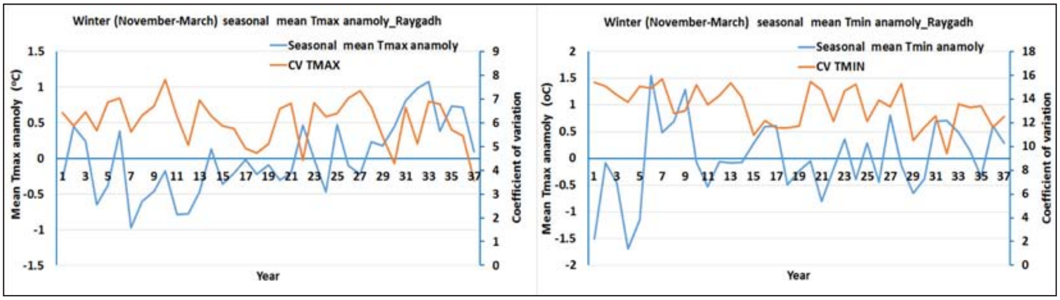


Fig. 13: Inter-annual variability in seasonal mean maximum and minimum temperature anomaly during winter season in Raigadh district. Intra-seasonal variability is indicated by the coefficient of variation.

Rainfall variability

Mewat: This district receives an annual rainfall of about 589 mm out of which ~500 mm occurs during monsoon season. However, a lot of inter-annual variation in total rainfall received during monsoon was noted. In order to get the spatial variability, block-wise analysis was done for blocks where the adaptation interventions were implemented. Results indicated not only inter-annual but also spatial variation for rainfall.

Past years analysis indicated that though mean rainfall ranged between 400-500mm in three blocks, inter-annual variability is very high. Maximum rainfall in a year ranged between 780-880 mm in three blocks (Fig 14). On the other hand, least rainfall years received less than 200mm rainfall. In a decade, 4 years received less than 80% of long-term mean rainfall in all four blocks while one year had just about 80% of long-term mean (Fig 15). Only three years received rainfall more than long-term mean, while remaining 2 years had rainfall between 80-100% of long-term mean. This indicates that the region is prone to severe drought stress. Analysis on the rainfall

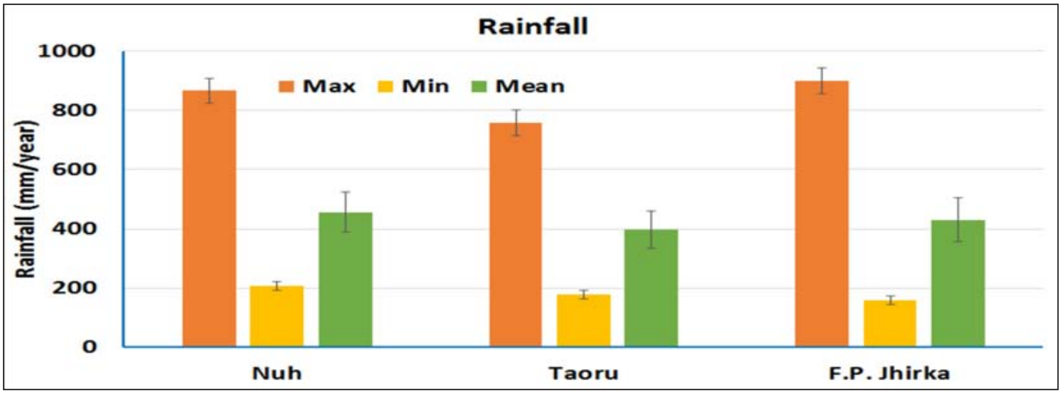


Fig. 14: Rainfall variation in different blocks of Mewat district.

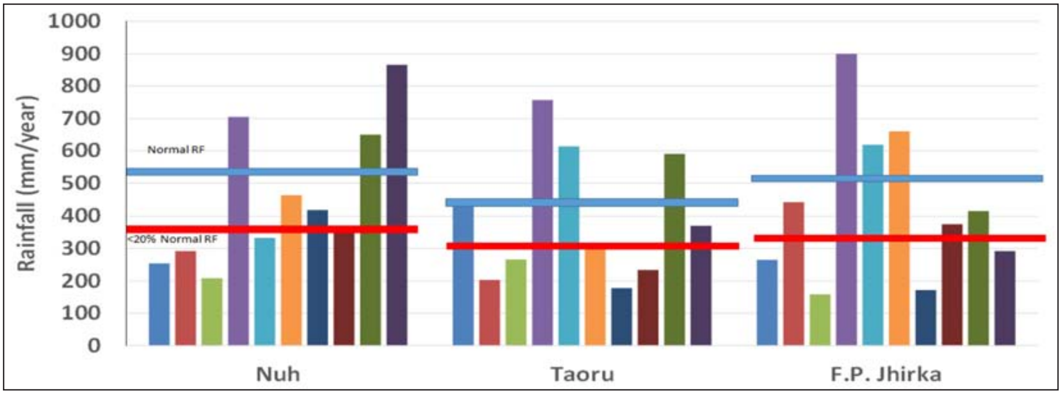


Fig. 15: Inter-annual variability in rainfall in different blocks of Mewat. The horizontal bars indicate threshold level of rainfall for normal and 20% less than normal (long-term mean) rainfall.

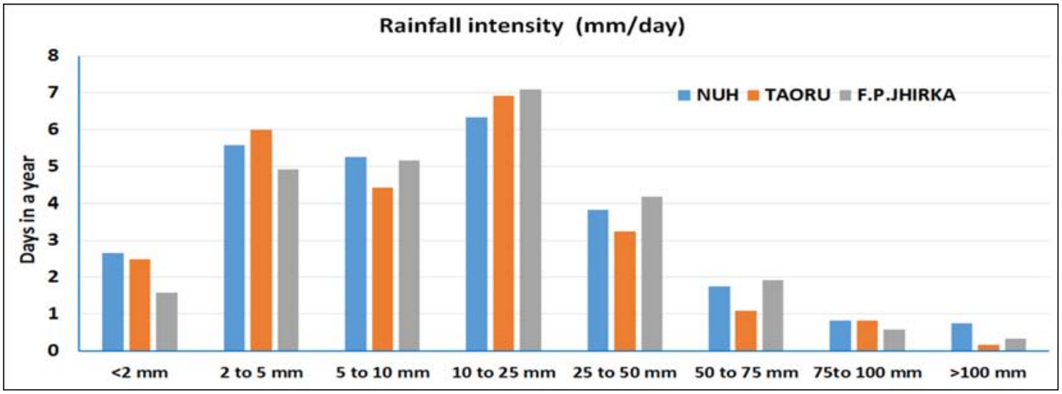


Fig. 16: Variability in rainfall intensity (mm/day) in different blocks of Mewat.

intensity indicated that blocks received mostly rainfall with an intensity in the range of 2 to 50 mm/ day (Fig 16). Rainfall events such as 50-75 mm and more than 75 mm in a day also occurred at a frequency of zero to three times in a year (Fig 16). This also indicates that in this region the quantity and frequency of high rainfall events are not as high as in some other regions.

Dhar: This district receives an annual rainfall of about 867 mm out of which 847 mm occur during monsoon season. In this district also, a lot of inter-annual variation in total rainfall received during monsoon was noted. Block-wise analysis indicated not only inter-annual variation but also spatial variation for rainfall (Fig 17).

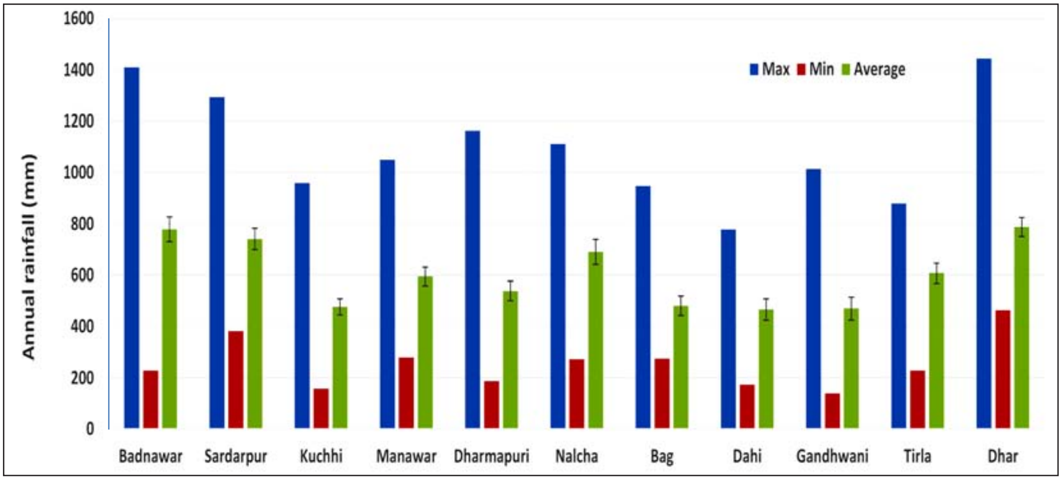


Fig. 17: Inter-annual and spatial variation in rainfall in different blocks of Dhar district.

Analysis of past 38 years data indicated that mean rainfall ranged between 790 and1440mm among 11 blocks in Dhar district (Fig 17). Among the blocks, minimum rainfall ranged between 150 and 410 mm, an indication of highly significant inter-annual as well as spatial variability (Fig 18). Four blocks, where interventions were implemented, had either very high rainfall years or dry years. Among these blocks, in a 38 year period only 8% (in two blocks), 13.5% and 20% of the years received normal rainfall. On the other hand 40-45% of the years received rainfall in excess of normal, while 31-48% of the years faced moderate to severe deficit in rainfall. This indicates that the region is not only prone to severe drought stress but also to high frequency of excess rainfall. Analysis on the rainfall intensity indicated that blocks received rainfall mostly with an intensity of 2 to 50 mm/ day. Rainfall events of 50 to 75 mm rainfall/ day occurred about 3 to 4 times/year, while over 75 mm rainfall/day also occurred up to three times in a year.

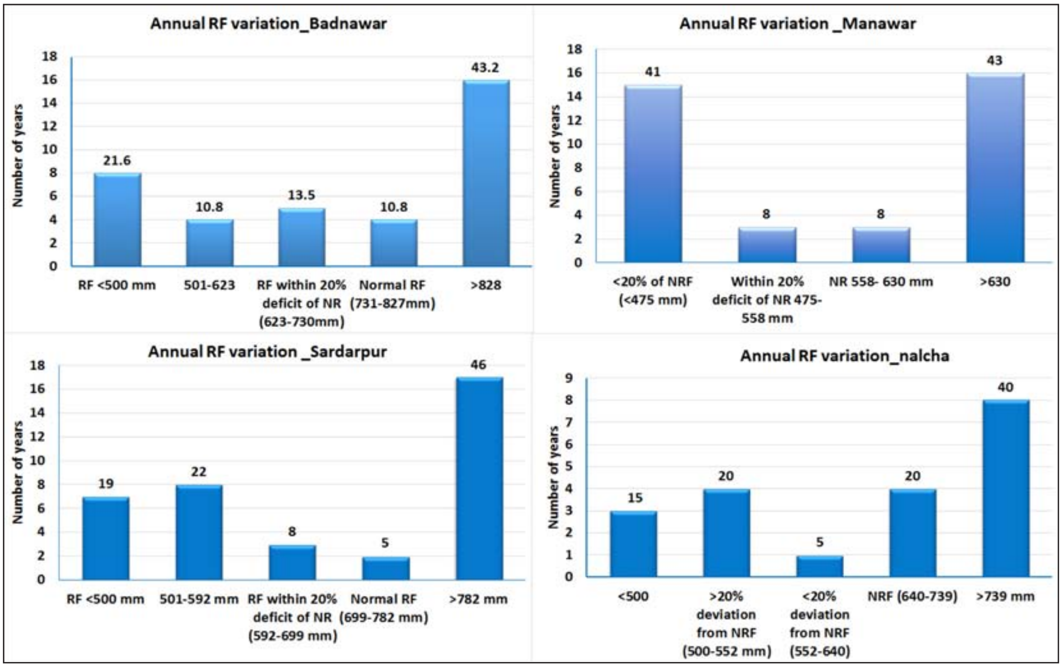


Fig. 18: Inter-annual variability in rainfall in different blocks of Dhar. The value above each bar indicates the percentage of years falling in that category. NR is normal (long-term mean) rainfall.

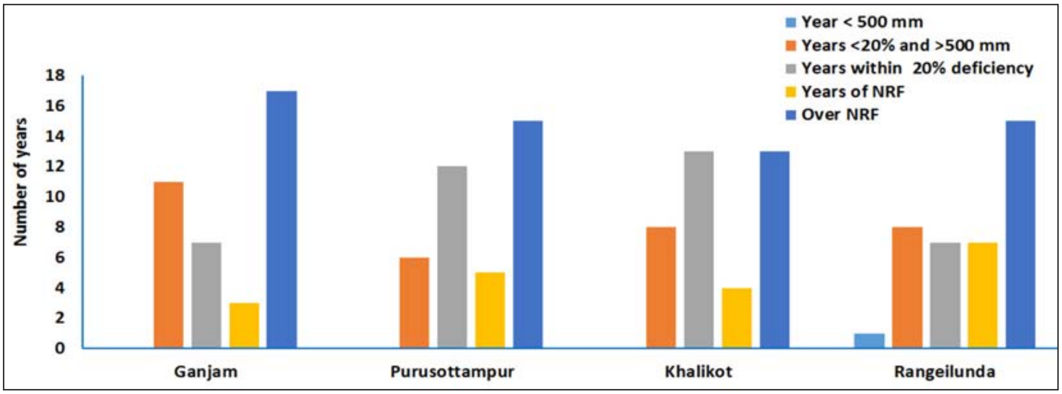


Fig. 19: Inter-annual variability in rainfall in different blocks of Ganjam. The value above each bar indicates the percentage of years falling in that category. NRF is normal (long-term mean) rainfall.

Ganjam: This district receives an annual rainfall of about 1150 mm out of which 1021 mm occur during monsoon season. This district also had the inter-annual and spatial variation for rainfall. Analysis of past 38 years data indicated that mean rainfall ranged between 1042 and 1371mm among 22 blocks in Ganjam district (Fig 19).

Minimum rainfall ranged between 316 and 859 mm. The rainfall data indicate that Ganjam district has high frequency of normal (long-term mean) and above normal rainfall years with occasional drought situation. Four blocks had generally very high rainfall years but with occasional low rainfall year. Only in one block, rainfall was less than 500 mm in one out of 38 years (Fig 19). During this period, 34-45% of the years received rainfall in excess of normal, while 8-18% of the years received normal rainfall and 18-34% of the years received rainfall 20% deficit than the long-term mean. Since rainfall amount is more with high frequency of heavy rainfall years, the region is prone to floods. Analysis on the rainfall intensity indicated that this region received rainfall mostly with an intensity in the range of 2 to 50 mm/day. High rainfall events such as 50-75 mm/day occurred on an average about 2-3 times and even up to 8 days in a year. Rainfall over 75 mm/day occurred between 1-5 events in year while rainfall over 100 mm/day occurred at a frequency of 1-3 events in a year. All these indicate this region as flood prone, particularly due to regions topography as well as because of the presence of Rishikula river. More analysis on flood risk in this district is discussed later.

Raigadh: This district receives an annual rainfall of about 2968 mm, bulk of which occurs during monsoon season (2939 mm). Past 38 years data analysis indicated that mean rainfall ranged between 3100 and 4700 mm among four blocks where the adaptation interventions were implemented. Minimum rainfall ranged between 529 and 1952 mm (Fig 20). The rainfall data indicate that Raigadh district has high frequency of years with normal and above normal rainfall, and a rare drought situation. However, all years had above 500mm of rainfall during past 38 years.

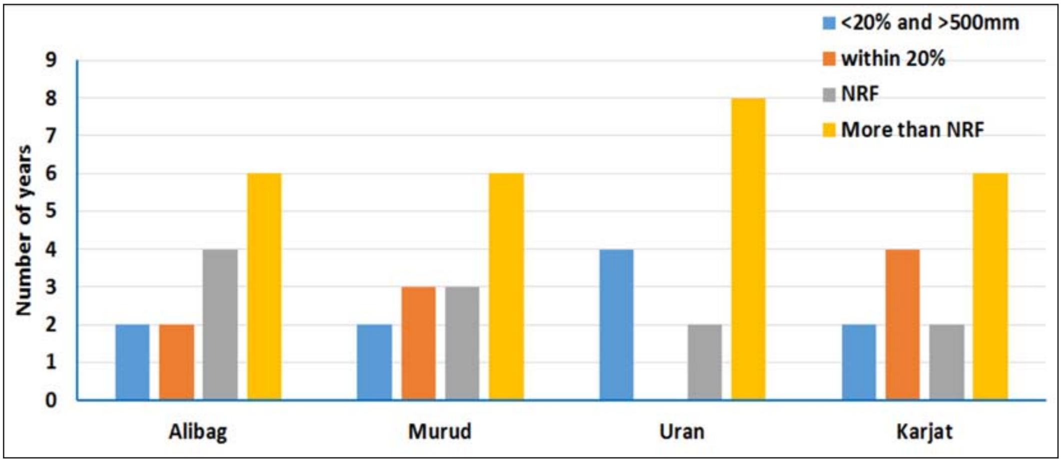


Fig. 20: Inter-annual variability in rainfall in different blocks of Raigadh. The value above each bar indicates the percentage of years falling in that category. NRF is normal rainfall.

During this period, 42.9-57% of the years received rainfall in excess of normal, while 14-28% of the years received normal rainfall. 14-28% of the years received within 20% deficit from the normal rain in three blocks, while in one block no such event occurred. Since rainfall amount is high with high frequency of heavy rainfall years, the region is prone to floods. Analysis on the rainfall intensity indicated that blocks received high rainfall events. This region received rainfall intensity of 50-75mm/day in about 8 days every year. Rainfall over 75 mm/day occurred between 1 and 5 events in a year while over 100mm/day occurred at a frequency of 1 to 3 events in a year.

Climate Change Projections

The block and district level analysis for climate change projection require high resolution data. The best available resolution data from the climate outputs of PRECIS (Providing Scenarios for Regional Impact Studies), a regional climate model, RCM) were used. The A1b emission scenario climate projections for 2030 (2020-2049) were analyzed and used for the impact and adaptation gain studies. The climate data outputs are of 0.5×0.5^{o} resolution. Apart from the climate change projections, the past climatology of different states, districts and blocks was delineated from IMD 1×1^{o} gridded data, derived from observed weather data, as well as from the point data for baseline period of past 30 years. The overview of the past climate and projected change in climate are presented state- and district-wise as well as season-wise.

Haryana (Mewat)

Monsoon season: In Haryana, seasonal mean maximum temperatures ranged from 30 to 36.5 ^{o}C while mean minimum temperatures ranged from 20 to 25 ^{o}C for monsoon (*Kharif*) season (Fig 21). In Mewat, these temperatures ranged from 34 to 35 ^{o}C and from 24 to 25

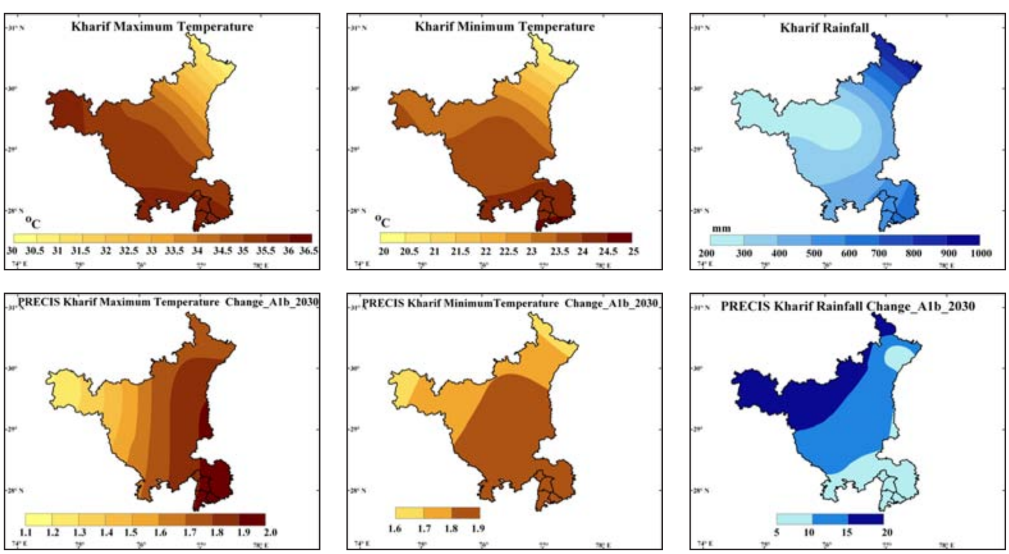


Fig. 21: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in monsoon season in Haryana in past 30 years. The lower panels show the increase in minimum and maximum temperature and change in rainfall in 2030 (mean of 2020-2049) in the A1b emission scenario.

°C, respectively. The rainfall during monsoon season in the state varied from 300 to 1000 mm while Mewat received around 600-700 mm.

Climate change is projected to increase the monsoon season mean maximum temperatures by 1.2 to 1.9°C in 2030 (2020-2049 period) in A1b scenario in Haryana (Fig 21). Similarly seasonal mean minimum temperatures are projected to increase between 1.6 and 1.9 °C. Rainfall during monsoon is projected to increase between 5 and 20% over the values presented for baseline. In Mewat, the projected change is 1.87 °C and 1.69 °C for seasonal mean minimum and maximum temperatures, respectively. Rainfall during monsoon is projected to increase by 6% in this district.

Winter season: The seasonal mean maximum temperatures ranged from 20.5 to 26.5 °C while mean minimum temperatures ranged from 7 to 10.5°C in winter (*Rabi*) season in Haryana. In Mewat, corresponding temperatures ranged from 25 to 26.5 °C and from 9 to 10.5 °C, respectively (Fig 22). The rainfall during winter season varied from 30 to 140mm in the state while Mewat received around 40-70 mm. Climate change is projected to increase the winter season mean maximum temperatures by 0.5 to 1.4°C in 2030 (2020-2049) in A1b scenario in Haryana (Fig 22). Similarly seasonal mean minimum temperatures are projected to increase between 1.9 and 2.3 °C. Rainfall during monsoon is projected to change between -5 and +35% over the baseline values. Climate change is projected to increase seasonal minimum and maximum temperatures by 2.16 °C and

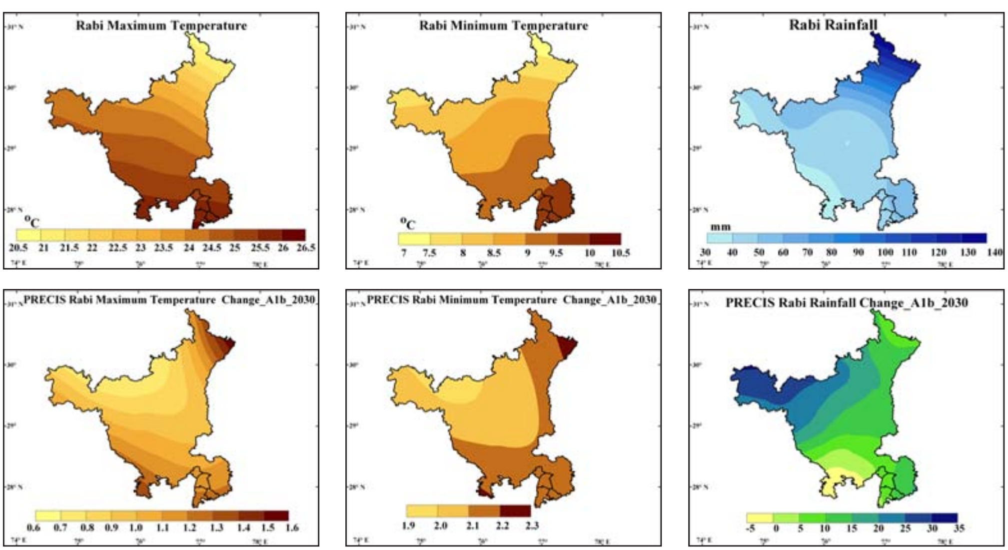


Fig. 22: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall during winter season in Haryana in past 30 years. The lower panels show the increase in minimum and maximum temperature and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

1.2 °C, respectively, in rabi season in Mewat district. The seasonal rainfall is projected increase by 9% over the baseline values of this district.

Madhya Pradesh (Dhar)

Monsoon season: In Madhya Pradesh, seasonal mean maximum temperatures ranged from 30.5 to 35 °C while mean minimum temperatures ranged from 21.5 to 24.5°C for monsoon (*Kharif*) season (Fig 23). In Dhar, these temperatures ranged between 32 and 32.5 °C and from 22 to 22.5 °C, respectively. The rainfall during monsoon season in Madhya Pradesh varied from 600-1500mm while Dhar received ~700-800 mm.

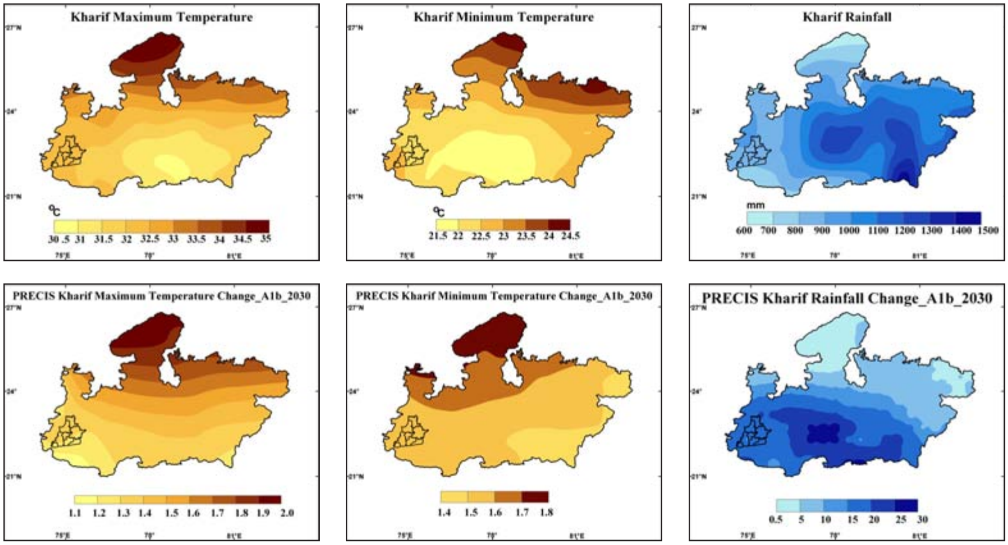


Fig. 23: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in monsoon season in Madhya Pradesh in past 30 years. The lower panels show the increase in minimum and maximum temperature and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

Climate change is projected to increase the monsoon season mean maximum temperatures by 1.1 to 1.9°C in 2030 (2020-2049) A1b scenario in Madhya Pradesh (Fig 23). Seasonal mean minimum temperatures are projected to increase between 1.4 and 1.8 °C. In Dhar district, seasonal mean minimum and maximum temperatures are projected to increase by 1.7 °C and 1.41 °C, respectively. Rainfall during monsoon is projected to increase between 0.5-30% in Madhya Pradesh and by 17% in Dhar district over the baseline values.

Winter season: The seasonal mean maximum temperatures ranged from 26 to 31 °C while mean minimum temperatures ranged from 9.5 to 15.5 °C during winter (*Rabi*) season in Madhya Pradesh (Fig 24). In Dhar, corresponding temperatures ranged from 28.5 to 31 °C and from 12.5 to 15.5 °C, respectively. Rainfall during winter season varied from 20 to 120 mm in the state, while Dhar received around 30-40 mm of rainfall. Climate change is projected to increase the winter season mean maximum temperatures by 1.4 - 2.2°C in 2030 (2020-2049) A1b scenario in Madhya Pradesh (Fig 24). Seasonal mean minimum temperatures are projected to increase between 2.1 and 2.7 °C, whereas winter rainfall is projected to change between -35 and +20% over the baseline values. In Dhar district, during rabi season projected increase in minimum and maximum temperatures are 2.73°C and 2.13 °C, respectively, while rabi rainfall is projected to reduce by about 22%.

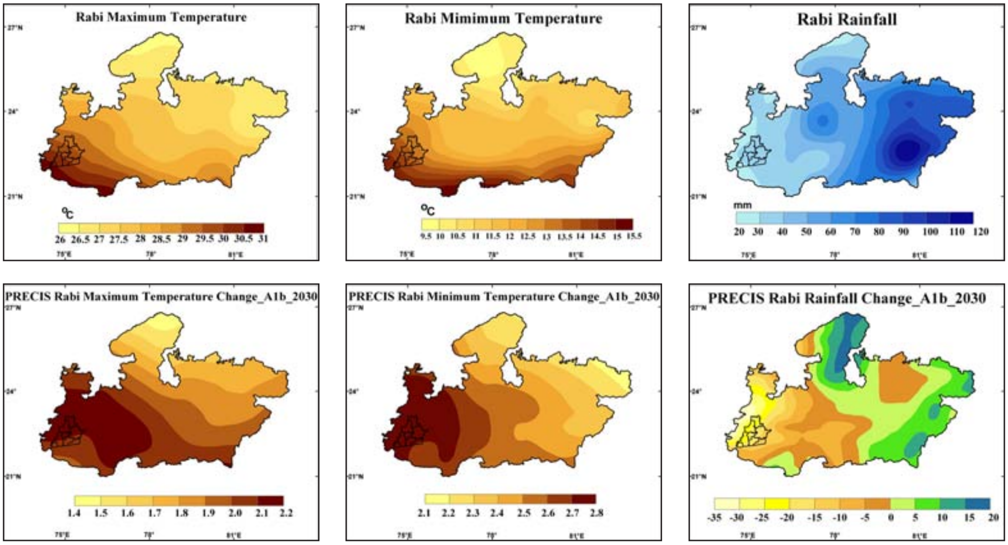


Fig. 24: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in winter season in Madhya Pradesh in past 30 years. The lower panels show increase in minimum and maximum temperature and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

Orissa (Ganjam)

Monsoon season: In Orissa, seasonal mean maximum temperatures ranged from 31-32.5 °C while mean minimum temperatures ranged from 22.5 to 25°C in monsoon (*Kharif*) season. In Ganjam, these temperatures ranged from 31.5 to 32.5 °C, and from 24 to 24.5 °C, respectively. The rainfall during monsoon season varied from 800-1400mm in Orissa, while Ganjam received about 900-1200 mm. Climate change is projected to increase the monsoon season mean maximum temperatures by 1.1 to 1.5°C in 2030 (2020-2049) A1b scenario in Orissa (Fig 25). Similarly seasonal

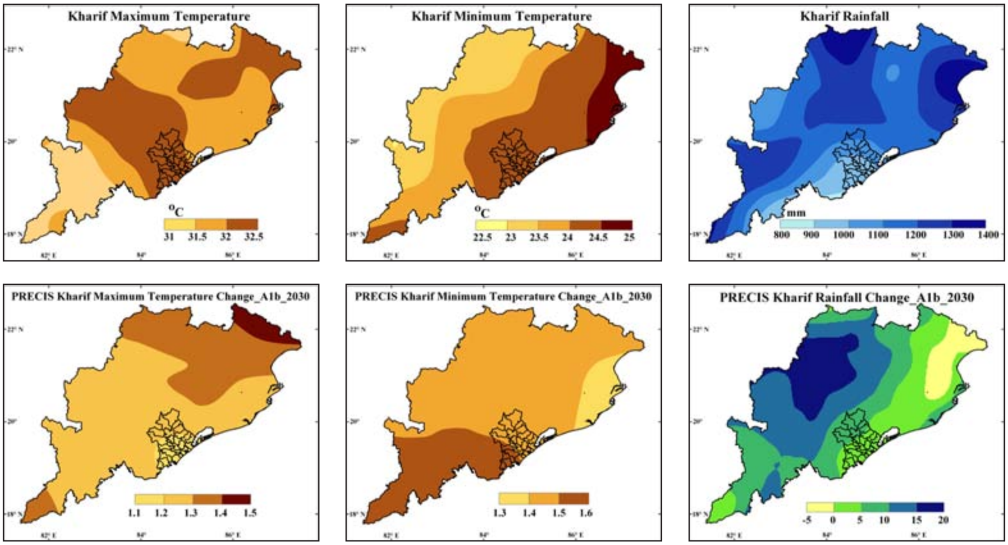


Fig. 25: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in monsoon season in Orissa in past 30 years. The lower panels show increase in minimum and maximum temperatures and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

mean minimum temperatures are projected to increase between 1.3 and 1.6 °C. Rainfall during monsoon is projected to change between -0.5 to +20% over the baseline period values. In Ganjam district, during monsoon season, minimum and maximum temperatures are projected to rise by about 1.49 °C and 1.35 °C, respectively. Monsoon seasonal rainfall is projected to increase by 6.5% in this district.

Winter season: The seasonal mean maximum temperatures ranged from 27.5 to 30 °C while mean minimum temperatures ranged from 13 to 20°C during winter (*Rabi*) season in Orissa. In Ganjam, these temperatures ranged between 29-30 °C and 16-18 °C, respectively (Fig 26). Rainfall during winter season varied from 30 to 150mm in Orissa, while Ganjam received between 100 and 150 mm. Climate change is projected to increase the winter season mean maximum temperatures by 1.7 - 2.4°C in 2030 A1b scenario in Orissa (Fig 26). Similarly seasonal mean minimum temperatures are projected to increase between 1.4 and 2.0 °C. Rainfall during monsoon is projected to change between -25 and +15% over the baseline values. In Ganjam district, during winter, minimum and maximum temperatures are projected to rise by 2.3 °C and 2.06 °C, respectively. Winter rainfall is projected to reduce by 9.5%.

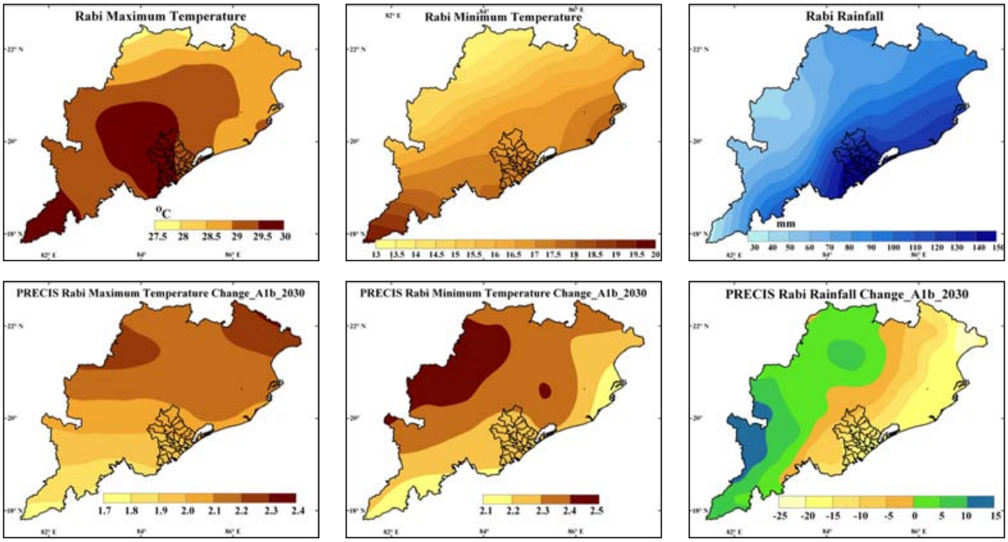


Fig. 26: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in winter season in Orissa in past 30 years. The lower panels show increase in minimum and maximum temperatures and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

Maharashtra (Raigadh)

Monsoon season: In Maharashtra, seasonal mean maximum temperatures ranged from 28 to 33 °C while mean minimum temperatures ranged from 20.5 to 24.5°C in monsoon (*Kharif*) season (Fig 27). In Raigadh, these temperatures ranged between 28.5-30 °C and 22.5-24.5 °C, respectively. Monsoon seasonal rainfall in Maharashtra varied from 400 to 4300 mm while Raigadh received ~2000-4300 mm. In Maharashtra, climate change is projected to increase the monsoon season mean maximum temperatures by 0.9-2.0°C in 2030 A1b scenario (Fig 27). Similarly seasonal mean minimum temperatures are projected to increase between 1.3 and 1.8 °C. Rainfall during monsoon is projected to change between -10 to +35% over rainfall in the baseline period. In Raigadh, mean seasonal minimum and maximum temperatures are projected to increase by 1.57 and 1.6 °C, respectively. Monsoon rainfall is projected to increase by 6%.

Winter season: The seasonal mean maximum temperatures ranged from 28 to 32 °C while mean minimum temperatures ranged from 13 to 20.5°C during winter (*Rabi*) season in Maharashtra (Fig 28). In Raigadh, these temperatures ranged between 29.5-30.5 °C and 16-20.5 °C, respectively. Rainfall during winter season in the state varied from 10 to 80 mm while Raigadh received around 10-30 mm. Climate change is projected to increase the winter season mean maximum temperatures by 1.8-2.23°C

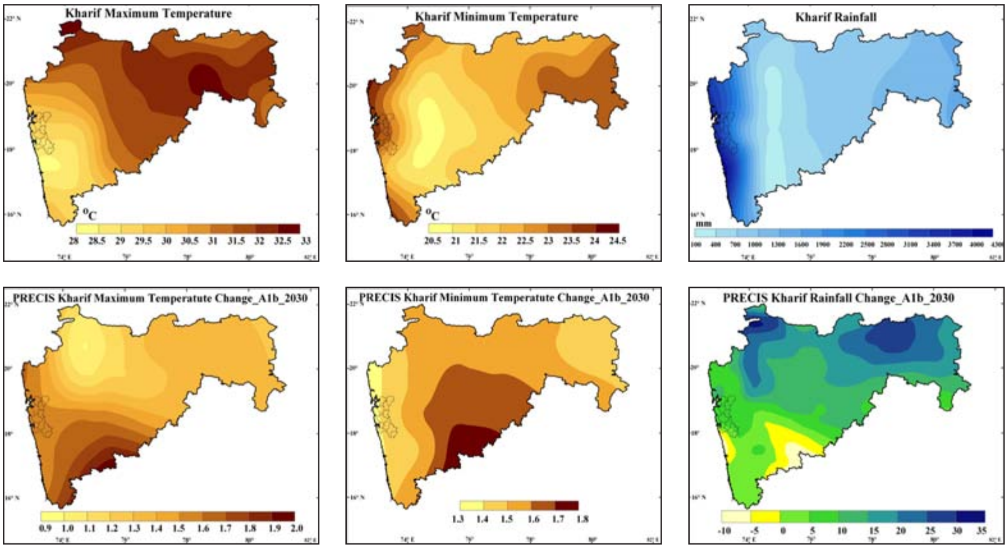


Fig. 27: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in monsoon season in Maharashtra in past 30 years. The lower panels show increase in minimum and maximum temperatures and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

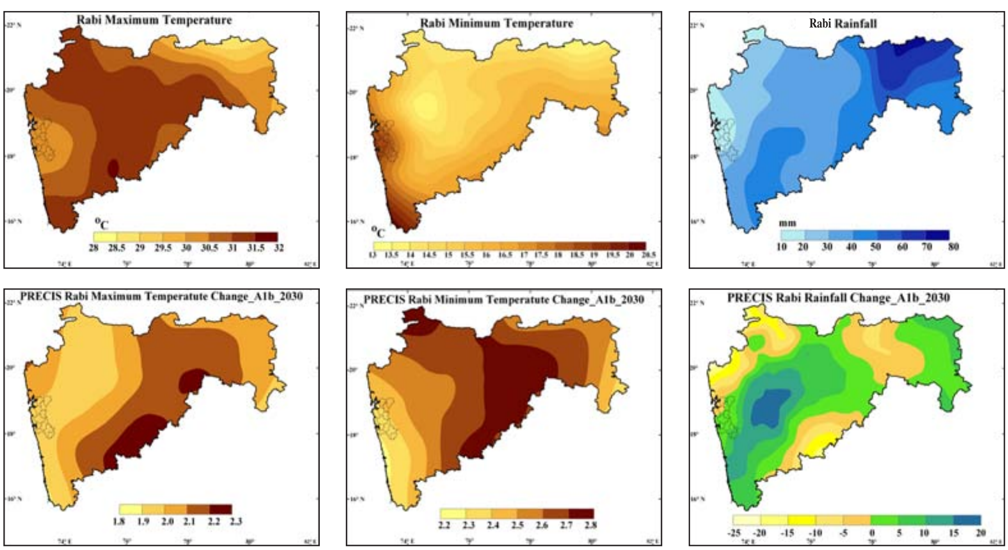


Fig. 28: Spatial variability in mean seasonal temperature (minimum and maximum) as well as rainfall in winter season in Maharashtra in past 30 years. The lower panels show increase in minimum and maximum temperatures and change in rainfall by 2030 (mean of 2020-2049) in the A1b emission scenario.

in 2030 A1b scenario in Maharashtra (Fig 28). Similarly seasonal mean minimum temperatures are projected to increase between 2.2 and 2.8 °C. Rainfall during winter is projected to change between -15 and +30% over the baseline values. In Raigadh, seasonal mean minimum and maximum temperatures are projected to rise by 2.47 and 1.99 °C, however no change in winter rainfall is projected.

Thus, an analysis of the PRECIS, a Regional Climate Model, out puts for 2030 (2020-2049) scenario indicated that the climate in these distracts is likely to be warmer, particularly during rabi season, in future (Table 2). Seasonal mean minimum temperatures during kharif are likely to increase in the range of 1.49 to 1.87 °C with a higher increase in Dhar and Mewat districts. Mean seasonal minimum temperatures during rabi season are projected to rise in the range of 2.16 to 2.73 °C. The mean seasonal maximum temperatures during kharif season are projected to rise in the range of 1.35 to 1.69 °C while during Rabi the increase is projected to be in the range of 1.2 to 2.13 °C. The kharif rainfall is projected to increase marginally in Mewat and Raigadh districts

Table 2: The characterization of climatic risks in past and projections in four districts.

Type of climatic risk /District (State)	**Mewat (Haryana)**		**Dhar (Madhya Pradesh)**		**Ganjam (Orissa)**		**Raigadh (Maharashtra)**	
Droughts in last 105 years (M=Moderate; S= Severe)	**18 M, 8 S**		**21 M, 3 S**		**5 M, 1S**		**(12 M, 1S)**	
	Kharif	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**	**Kharif**	**Rabi**
Temperature increase in past 40 years Tmin (°C/10 years) Tmax (°C/10 years)	0.18 -0.003	0.47 -0.12	0.07 0.001	0.1 0.17	-0.10 -0.07	0.13 0.13	0.04 0.12	0.08 0.26
Rainfall (mm) Past change in rainfall (%)	583 -1	43.9 32	858 -19	28 -54%	1097 7	120 16%	2546 6	20 -70%
Future (2020-2049 scenario) change in temperature T min (°C) T max (°C)	1.87 1.69	2.16 1.2	1.7 1.41	2.73 2.13	1.49 1.35	2.3 2.06	1.57 1.6	2.47 1.99
Future (2020 -2049 scenario) change in rainfall (%)	6	9	17	-22	6.5	-9.5	6	No change
Overall climatic risks T-Temperature stress D-droughts F- Floods WL- Water logging	T and D	T	T and D	T	F and WL	T	F and WL	
Major cropping system	Millets/ pulses vegetables / fodder sorghum-wheat/mustard		Cotton/ Soybean-Wheat/chickpea		Rice/ pulses		Rice/pulses/ millets	

and substantially in Ganjam district, whereas, rabi rainfall is projected to reduce in Dhar and Ganjam districts. On the other hand no change in rabi rain fall is projected for Raigadh district.

From the baseline and climate scenarios data, yearly and seasonal temperatures for four districts in present and future climates are given in Table 3.

Table 3: The climate in past and future projections for four districts.

District		1969-2005 period			2020-2049 period (2030 scenario)	
		Yearly	Kharif	Rabi	Kharif	Rabi
Mewat	T min (°C)	18.1	24.3	10.0	26.1	12.2
	T max (°C)	31.8	35.2	25.6	36.9	26.8
	Rainfall (mm)	653	584	43.9	619	47.8
Dhar	T min (°C)	19.0	22.6	13.4	24.3	16.1
	T max (°C)	32.7	32.4	30.1	33.9	32.3
	Rainfall (mm)	893	858	28.0	1004	21.9
Ganjam	T min (°C)	21.4	24.1	17.1	25.6	19.4
	T max (°C)	32.2	32.3	30.1	33.6	32.2
	Rainfall (mm)	1299	1097	119.5	1168	108.2
Raigadh	T min (°C)	20.7	22.8	17.5	24.4	19.9
	T max (°C)	31.3	29.9	31.3	31.5	33.3
	Rainfall (mm)	2584	2547	19.8	2699	19.8

Climatic extremes analysis projections

Temperature extremes

The temperature extremes were worked out for four districts by analyzing the daily weather data from 1969 onwards. Results indicated that in Mewat heat waves occurred with temperatures above 40°C during monsoon season (Fig 29). A significant decreasing trend in days with less than 5 °C as well as days with less than 10 °C during winter season was noted, indicating a warming trend. In Dhar, an increasing trend in days with more than 30°C was noted during monsoon as well as winter season. On the other hand, days with less than 10 °C have been decreasing during winter, as in case of Mewat.

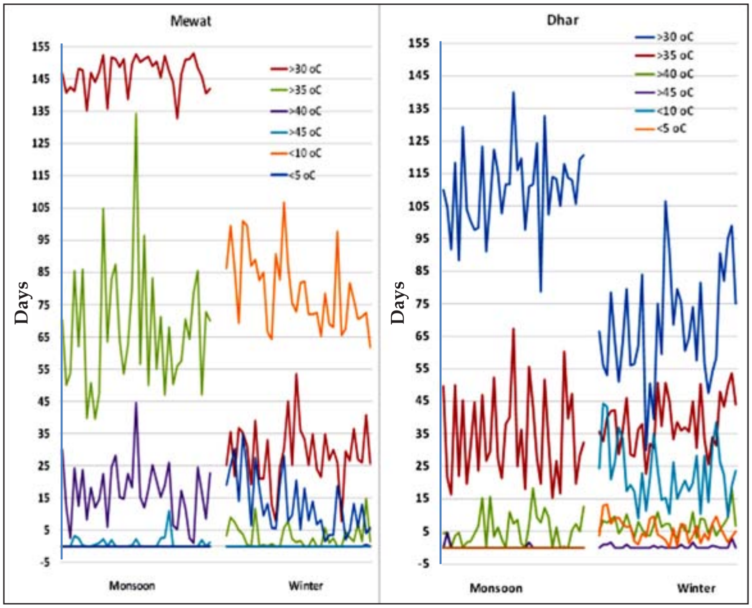


Fig. 29: Temporal variability in high temperature events during monsoon and winter seasons in Mewat and Dhar districts.

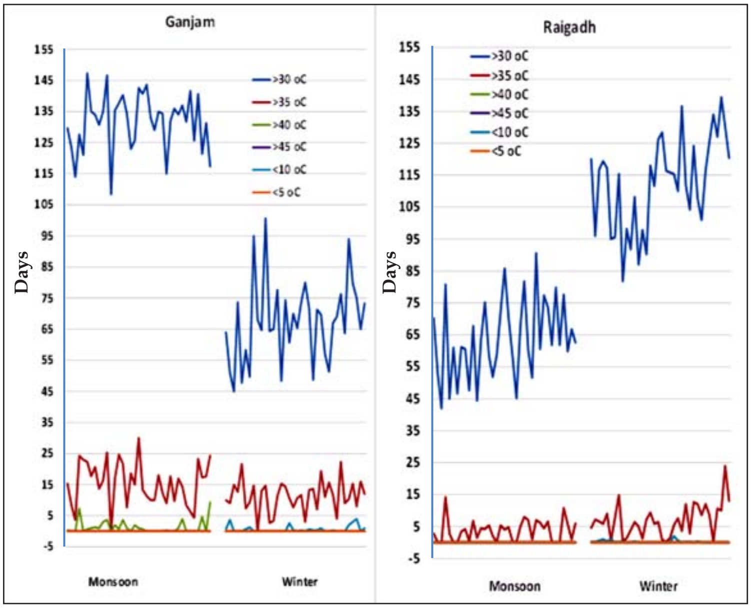


Fig. 30: Temporal variability in high temperature events during monsoon and winter seasons in Ganjam and Raigadh districts.

Similar analysis for Ganjam indicated occurrence of heat waves with temperatures above 40 °C during monsoon season (Fig 30). During winter season, number of days with temperatures above 30 °C found to increase. In Raigadh, a significant increase in number of days with temperatures above 30°C have been noted for both monsoon as well as winter season. Temperatures above 35 °C also have been increasing, particularly during post-monsoon (winter season) period.

Trends in high temperature events: Analysis indicated a general increasing trend in days with high temperatures and a decreasing trend in days with low temperatures (Table 4). Warming trends are more for winter season.

Table 4. The trends of days with high and low temperature events.

District	Trends in days with long-term mean (normal) and extreme temperatures												
	Period	>30 °C		>35 °C		>40 °C		>45 °C		<10 °C		<5 °C	
		Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
Mewat	Yearly	-0.01	0.02	0.07	0.04	-0.05	0.03	0.01	0.01	-0.54	0.32	-0.49	0.34
	Monsoon	0.07	0.03	0.08	0.03	-0.11	0.03	0.01	0.01	0.00	0.00	0.00	0.00
	Winter	0.01	0.01	-0.01	0.01	0.00	0.04	0.00	0.00	-0.60	0.27	-0.50	0.33
Dhar	Yearly	0.75	0.17	-0.01	0.00	0.00	0.00	-0.01	0.04	-0.25	0.05	-0.02	0.07
	Monsoon	0.28	0.05	-0.01	0.00	0.07	0.03	-0.02	0.02	0.00	0.00	0.00	0.00
	Winter	0.55	0.12	0.04	0.00	0.02	0.02	0.00	0.00	-0.33	0.08	-0.01	0.06
Ganjam	Yearly	0.26	0.03	-0.02	0.00	-0.01	0.02	0.00	0.00	0.02	0.01	0.00	0.00
	Monsoon	0.04	0.00	-0.06	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00
	Winter	0.33	0.07	0.05	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00
Raigadh	Yearly	1.01	0.24	0.57	0.21	0.00	0.00	0.00	0.00	-0.01	0.02	0.00	0.00
	Monsoon	0.40	0.11	0.05	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Winter	0.70	0.23	0.19	0.18	0.00	0.00	0.00	0.00	-0.01	0.04	0.00	0.00

All the above mentioned changes in temperatures and rainfall along with changes in other associated weather conditions have been affecting the agricultural productivity in these districts. These risks are projected to be more in future climatic conditions (Fig 31) exerting greater influence on agricultural and livelihood security of farming community in these regions.

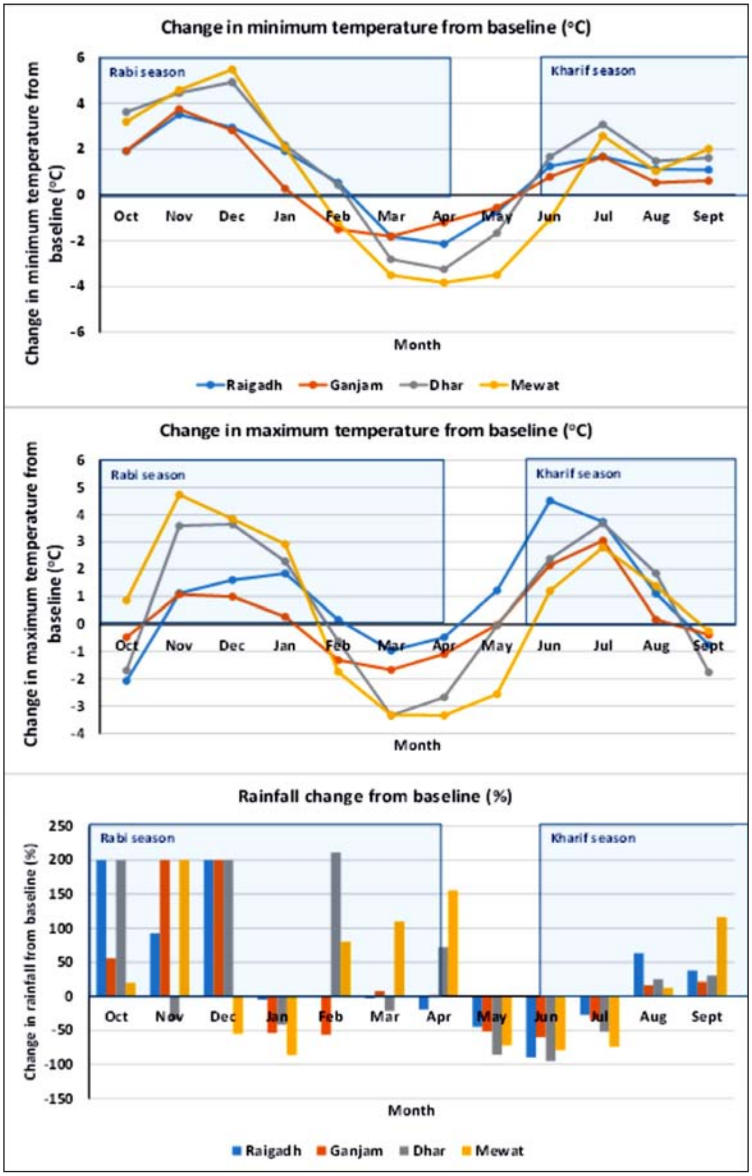


Fig. 31: Projected change in monthly mean minimum, maximum and monthly total rainfall in four districts.

Mapping Flood Prone Zone in Ganjam

Climatic parameters influence the agriculture directly as well as indirectly in several ways. For instance, water logging and flooding severely affect the agriculture and livelihoods of people dwelling in low-lying or flood prone zone areas. Since Ganjam district is flood prone among four districts, a modeling analysis was carried out to map the flood affected areas in the district.

During monsoon season, dry spells and heavy rainfall events are projected, with likely increase in high rainfall events and occurrence of floods. The flood plain zone in Ganjam due to increase in river level was modeled using the Hydrologic Engineering Center-River Analysis System (HEC-RAS, version 4.1.0) model and Global Elevation Model (GEM).

Data and methodology

For the flood plain zone mapping, HEC-RAS model was used. Spatial data input for HEC-RAS model was developed from digital terrain models and other GIS datasets. After the model results are calculated in HEC-RAS, post processing is done in HEC-GeoRAS and then the floodplain water depths and extents are mapped. HEC-RAS is a one-dimensional, steady-flow, water surface profile modeling program which is capable of modeling a full network of channel, a dentric system or a single river reach. It requires the definition of the land surface to be modeled and flow data for hydrologic events. In the model, geometric and flow data are used to calculate steady and gradually varied flow water surface profiles from energy loss computations. This model is utilized for analyzing the topography of the region and delineating the floodplain zones for flood modeling. Besides floodplain mapping, its results can be used for flood damage computations, ecosystem restoration and flood warning response and awareness.

For the analysis, digital elevation model data of GMTED2010 were used. The new elevation products have been produced following aggregation methods of minimum elevation, maximum elevation, mean elevation, median elevation, and standard deviation of elevation, systematic subsample, and break line emphasis. Using this data the triangulated irregular network (TIN) was created. For classification of agricultural and non-agricultural area, the Landsat 5 satellite images (path 140 and row 46-47 with 30 m resolution data, dated 31st October 2009) were used. This data were also used for correcting the geometric layers of river system. Further, the District Disaster Management Plan of Ganjam (DDMA 2012-13) was referred to locate river gauge stations. For inundation mapping first the WSTIN was converted to water depth grid. The water depth grid was used to evaluate the floodplain zone at 0.5m interval. In ArcGIS, raster reclassification was used for flood plain zone at different water level increases (at 0.5 meter interval) from the river bank. The water depth grid was also used for contour mapping for delineating flood plan zone at different water levels.

Flood plain zone in Ganjam

The analysis indicates that in Ganjam, about 1 lakh hectares area is flood prone with river level increase to 4.5 m above normal level (Fig 32). Ninety percent of this area is agricultural land. It is also found Aska as the first flood-prone area (Fig 33). This may be used as the alarming signal for flooding in other areas in Ganjam.

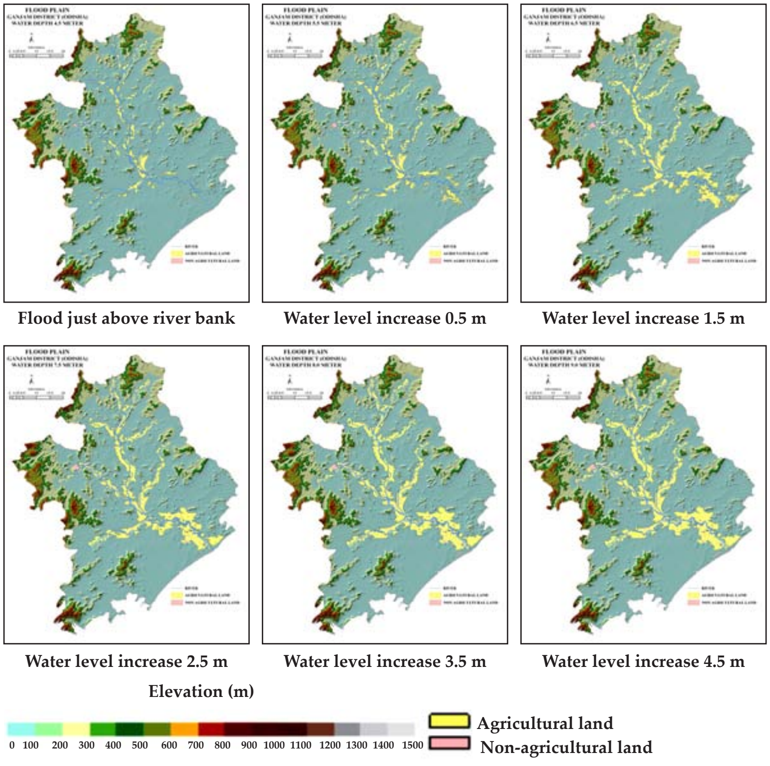


Fig. 32: Flood-plain zone in Ganjam district at different levels of Rishikula river water. The flood-prone area under agricultural land is also delineated.

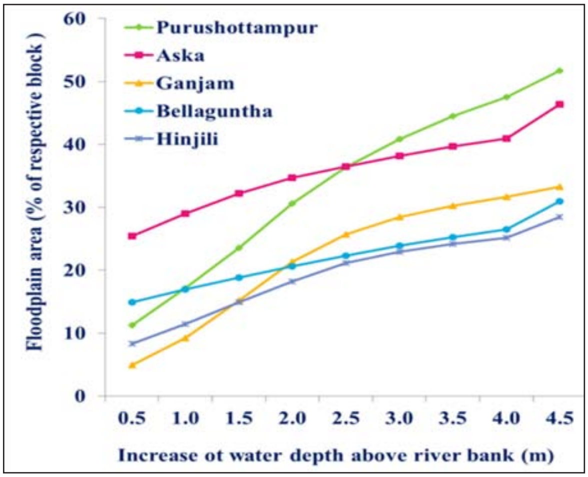


Fig. 33: Flood-prone areas of Ganjam due to different levels of water in Rishkula river.

From the above climatic data analysis, the major climatic risks in four districts identified were: i) temperature/heat stress and droughts in Mewat and Dhar districts, ii) temperature and flood stress in Ganjam district and iii) heavy rains and floods in Raigadh district. The adaptation strategies were worked out to address these climatic risks in the project area. For developing the adaptation strategies, these stresses were given importance based on the current cropping system in the region, base climatic data and projected changes. Before developing the adaptation strategies, bio-physical characterization and the land use and land cover analysis was carried out for Mewat and Dhar districts.

Bio-physical Characterization of Mewat and Dhar Districts

Mewat, Haryana

District Mewat was created by carving out of Gurgaon and Faridabad districts in Haryana during April, 2005. Having an extent of 1874 sq km, Mewat district is surrounded by the Gurgaon in north and Faridabad in east, Rajasthan state in west and south. The district has three distinct agro- ecological situations (Fig 34 and Table 5; Source: Report of ATMA, Mewat 2008).

Though soils are sandy loam, there exists a significant spatial variation for various soil parameters of Mewat (Department of Agriculture, Mewat, Haryana). The soils are saline in some parts of Mewat district while in some places they have alkaline pH

Fig. 34: Agro-ecological situations in Mewat District of Haryana (Source: Report of ATMA, Mewat 2008).

Table 5. Description of agro-ecological situations in Mewat District, Haryana (Source: Report of ATMA, Mewat 2008).

AES No.	Name of Agro Eco Situation	Description of Agro-ecological situation	Block covered	Representative village
I	Average rainfall, sandy loam soil, assured irrigation (tubewell)	This situation spreads over all of block Taoru having 12.17% of cultivated area. Bajra is the major crop in kharif and wheat in rabi. There is bajra-wheat based cropping pattern	Taoru	Dingerheri
II	Medium rainfall, sandy and sandy loam soil, assured irrigation (tubewell and canal)	This situation is predominate in block Hathin and Punhana having 35.7% cultivated area; assured irrigation. The main crop grown is rice and bajra in kharif and wheat and mustard in rabi. Sugarcane is grown wherever supplemented by tubewell irrigation	Hathin and Punhana	Puthli
III	Low rainfall, sandy and sandy loam soil, the lower layer of this reasons is salt effected.	This situation is spread in block Nuh, F.P. Jhirka, and Nagina having 52.06 cultivated area there are unassured irrigation, ground water quality is not good. The main crop is grown in rainfed condition. Main crop is jowar and bajra in kharif and wheat and mustard in rabi. Kharif onion is the major crop for horticulture	Nuh, F.P. Jhirka and Nagina	Khedli Kalan

(Fig. 35a and b). The soils are low in soil organic carbon (SOC) (less than 0.4%) except in small patches where the SOC ranged between 0.4 and 0.75% (Fig 35 c).

Soils are poor in available nitrogen except in some places where they are having medium level of nitrogen availability (Fig 35 d). Mewat soils are poor in available phosphorous (Fig 35 e), but are generally good in available potassium (Fig 35 f), but in some regions, the level of available potassium is medium to low.

Mapping land use and land cover change

Land use land cover mapping and its change detection during 1998-2005 was done using multispectral Indian remote sensing data for three years i.e., 1998, 2002 and 2005. Pre-processing including geometric and radiometric corrections were performed before doing further analysis for change detection. Land use cover change detection was done using two approaches such as NDVI (Normalized Difference Vegetation Index) image based pre-classification and post-supervised classification.

The Normalized Difference Vegetation Index gives a measure of the vegetative cover on the land surface over wide areas. It provides a crude estimation of vegetation health and a means of monitoring changes in vegetation over time. Multispectral remote sensing data is the most well-known and NDVI is used to detect live green plant canopies. Vegetation differs from other land surfaces because it tends to absorb

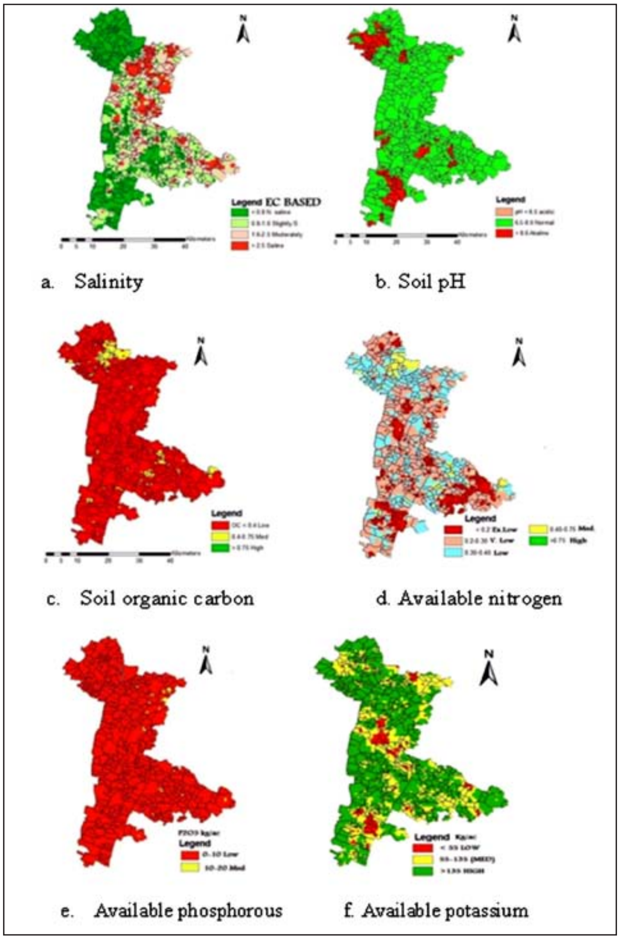


Fig. 35: Spatial variation in soil nutrient status and soil properties in Mewat district.

strongly the red wavelengths of sunlight and reflect in the near-infrared wavelengths. The NDVI is calculated as

$$NDVI= (R_{NIR} - R_{Red})/(R_{NIR} + R_{Red}) = (B3 – B2)/(B3 + B2)$$

Where R_{NIR} and R_{red} are reflectances in NIR and Red regions, and in case of image it is digital number in respective bands. Vegetation change detection analysis was done by computing difference in NDVI of two years and classified into three categories such as high change, medium change, and no or very less change, which indicate spatial change in vegetation cover over previous years.

For Mewat district, three dates images of the years 1998, 2002 and 2005 of winter season were analyzed and classified images are given in Fig. 36, as well as its statistics is given in Table 6.

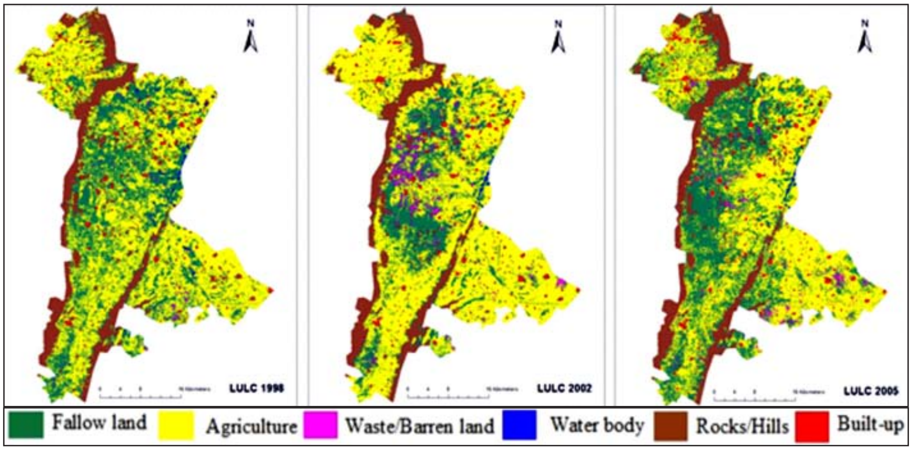


Fig. 36: Land use land cover maps of Mewat district during the year (a) 1998 (b) 2002 and (c) 2005.

Table 6: Land use land cover (area in percentage of total area of the district) statistics of Mewat during 1998, 2002 and 2005.

Land use land cover	1998 (area %)	2002 (area %)	2005 (area %)
Agriculture	57.46	67.31	53.98
Fallow land	41.16	29.48	43.91
Waste/Barren land	0.67	2.63	1.95
Water body	0.66	2.63	1.97
Built-up	3.43	3.87	4.63
Rocks	15.54	15.54	15.54

The NDVI differencing technique was used to analyze the amount of change in vegetation versus non-vegetation with the three temporal data sets and is given in Fig 37.

Change detection matrix was calculated to retrieve information regarding change in area for each class of 1998 to corresponding change in area for all classes in 2005 and results are shown in percentage values (Table 7). Analysis indicated (i) decrease in agriculture by 3.49% between year of 1998 and 2005, (Fig 38) (ii) increase in fallow land by 2.75% between year 2002 and 2005 and a noticeable decrease of 11.68% between year 1998 and 2002, (iii) increase in trend of built-up area with 0.44% between year 1998-

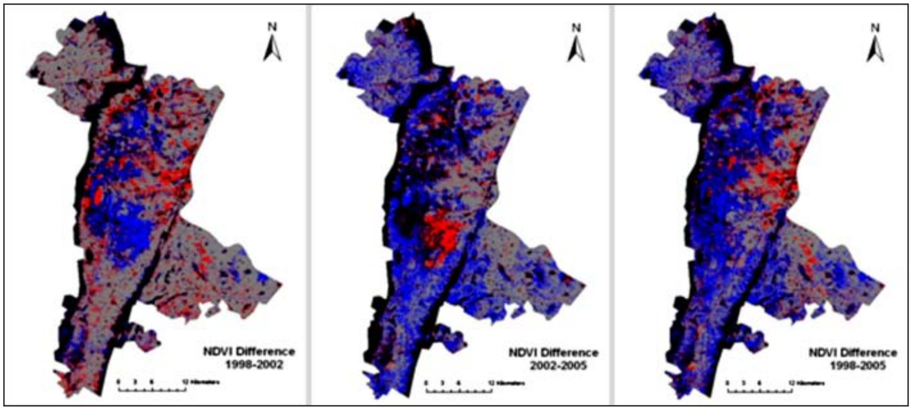


Fig. 37: NDVI difference map of Mewat district for (a) 1998-2002 (b) 2002-2005 (c) 1998-2005.

Table 7: Change detection matrix for land use land cover of Mewat.

		Initial Stage-1998				
Final Stage-2005		**Agriculture**	**Fallow land**	**Water body**	**Waste/Barren land**	**Built-up**
	Built-up	1.72	4.20	15.26	1.70	99.0
	Agriculture	61.8	40.3	30.0	35.2	0.44
	Waste/Barren land	1.09	2.68	0.21	20.90	0.04
	Fallow land	35.30	52.63	40.68	42.19	0.49
	Water body	0.048	0.226	13.867	0.061	0.004
	Class Total	100	100	100	100	100
	Class Changes	38.16	47.37	86.1	79.10	0.97
	Image Difference	-7.22	5.47	-69.44	193.52	0.66

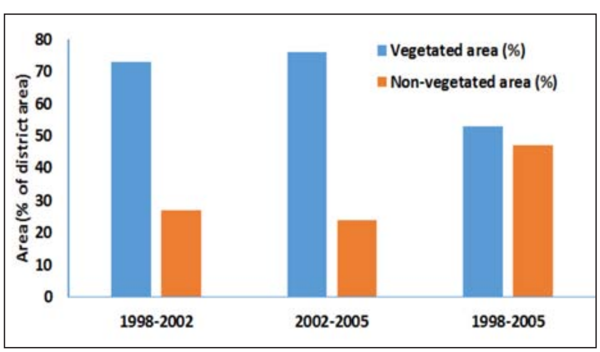


Fig. 38: Change in vegetation area (including agriculture) of Mewat district of Haryana in different years.

2002, 0.76% between year 2002-2005 and 1.20% between year 1998- 2005, (iv) changes in water bodies are not significant and (v) varying trend of waste/barren land with an increase of 1.96% between year 1998-2002, decrease of 0.67% between year 2002-2005 and increase of 1.29% between year 1998- 2005.

Dhar, Madhya Pradesh

Dhar district of Madhya Pradesh is geographically extended from 22°002 to 22°492 N latitude and from 75°062 to 75°422 E longitude covering an area of 8,153 km². The district extends over three physiographic divisions viz., the Malwa in the north, the Vindhyachal range in central zone and the Narmada valley along the southern boundary. However, the valley is again closed up by the hills in the south-western part. The Vindhya Range runs east and west through the district. The northern part of the district lies on the Malwa plateau. The northwestern portion of the district lies in the sub-basin of the Mahi River and its tributaries, while the northeastern part of the district lies in the sub-basin of the Chambal River, which drains into the Ganges via the Yamuna River. A portion of the district in south ridge of the Vindhyas lies in the sub-basin of the Narmada River, which forms the southern boundary of the district.

Majority of Dhar soils have a pH in the range of 7.1-7.5, while patches of soils with pH 6.5-7 are spread across Dhar (Fig 39). The soil organic carbon status of Dhar district varied between 0.28 to 0.75 %. There have been patches of soils with low (0.15-0.25%) soil organic carbon (SOC) across the state (Source : Soil resource atlas of Dhar, NBSS&LUP, 2001).

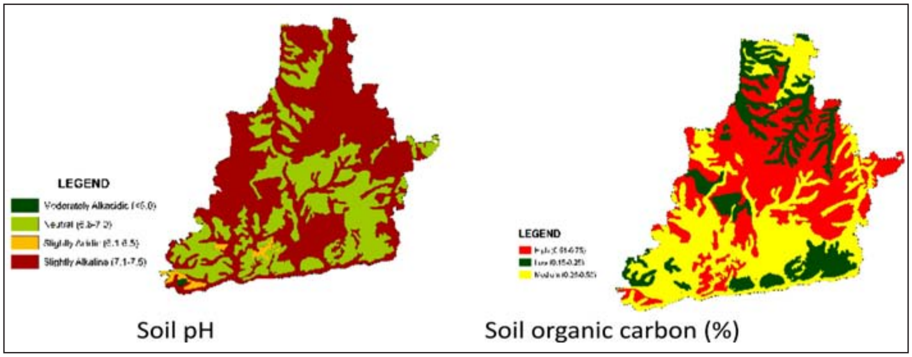


Fig. 39: Spatial variation in soil pH and SOC in Dhar district (Source : Soil resource atlas of Dhar, NBSS&LUP, 2001).

The soil suitability map of Dhar indicated high suitability for wheat and soybean in north-west and southern parts of the district (Fig 40). The central part is dominated

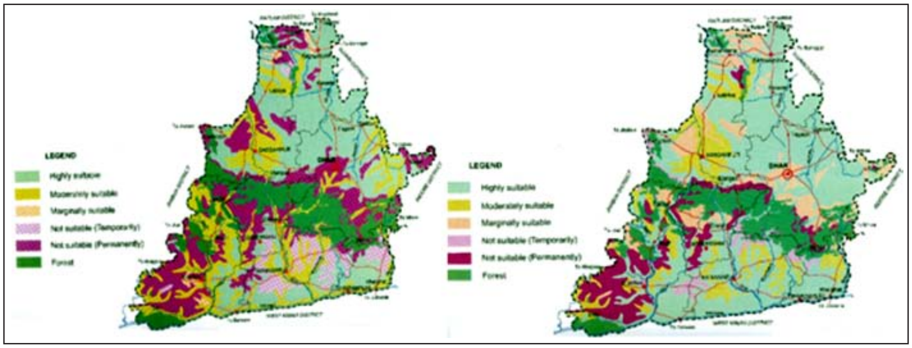


Fig. 40: Soil suitability map of Dhar, MP for wheat and soybean crops (Source : Soil resource atlas of Dhar, NBSS&LUP, 2001).

by the forest area while the south- west part of Dhar is generally not suitable for cultivation of these crops.

Following the earlier described methodology, land use land cover mapping and its change detection during 1998 to 2002 was done for Dhar district using multispectral Indian remote sensing data acquired during *rabi* season (February) of both the years. Pre-processing including geometric and radiometric corrections were performed before doing further analysis for change detection. Based on NDVI image and its classification it was found that 40.99% area was under vegetation and 50.01% area was under non-vegetation for year 1998 and in the year 2002, 10.24% area was under vegetation and 89.76% area was under non-vegetation (Fig 41&42).

The post classification change detection method is one of the most widely used methods of remote sensing change detection. Differencing of classified images (using supervised image classification technique) multispectral of six land use cover classes (Agriculture, fellow land, vegetation, built up, water body, waste land) was done to

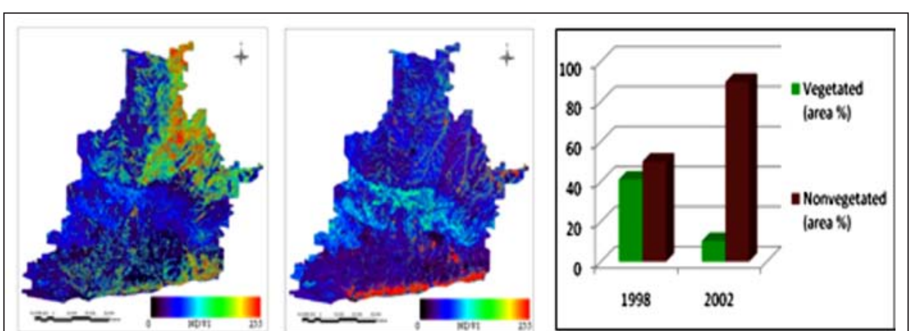


Fig. 41: NDVI Map of Dhar district for year 1998 and 2002and vegetation cover class statistics.

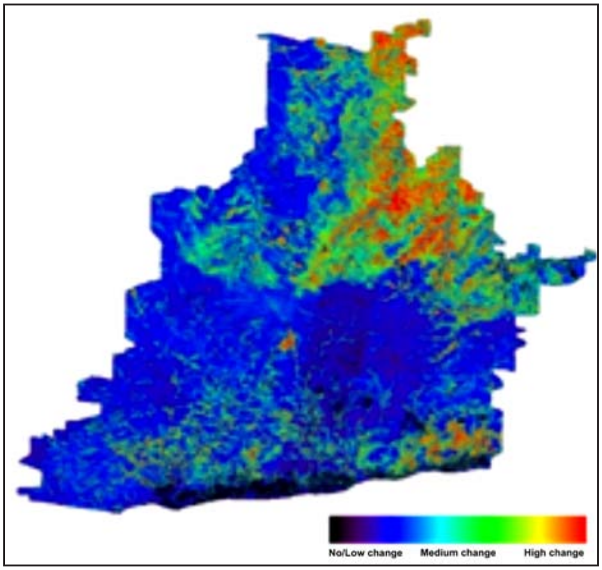


Fig. 42: NDVI difference map of Dhar during year 1998 to 2002 indicating change in vegetation cover.

have change matrix of the classes. The accuracy assessment each classified image was done having Kappa coefficient 0.81 and 0.92 for the years 1998 and 2002, respectively. Fig 43 indicates classified image of the both the years and change in land use and cover (as percentage of area of under class) is given in Table 8.

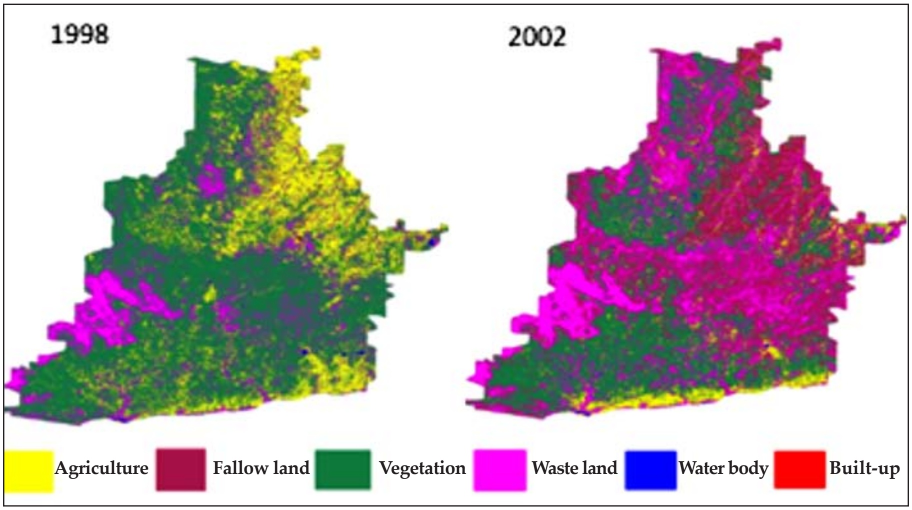


Fig. 43: Land use land cover map of Dhar district for year 1998 and 2002.

Table 8: Change statistics of Land Use/Land Cover of Dhar during the years 1998 and 2002.

Land use/Land cover categories	Change (area in %)
Agriculture	-11.98
Vegetation	-28.28
Fellow Land	29.98
Built-Up	0.03
Waste Land	11.28
Water Body	-0.12

Dominant change which occurred in the study area was in the fallow (29.98%) and agriculture –(11.98%) land. Increase in built-up (0.03%) and waste (11.28%) land were observed during the period. Natural vegetation is predominantly covered in the study area where human activities are relatively less intense. There has been a declining trend of 28.28 % in vegetation area during 1998-2002 period. Most of the agriculture land was converted into fallow land and waste land during this period.

Baseline Status of Agriculture and Farming Community in Mewat and Dhar Districts

Climatic variability and extreme events in recent past have emerged as potential threats to rural livelihoods. Consequently, adaptation has assumed a greater significance and is of high priority across the Nations. A socio-economic analysis was carried out to delineate the baseline status of the farming community of Mewat and Dhar districts before adaptation strategy was developed.

Following are the key issues related to farming and livelihood security of the farmers in these two districts.

1. The focus group discussions with the farmers as well as the past climate data analysis revealed drought and heat stress as the major thriving risks in the area.
2. Decreasing amount of rainfall marked with irregular distribution and untimeliness as well as it's early withdrawal aggravated their problems.
3. Excessive evaporation affected the crop growth and yield as irrigation is a serious limitation in the area.
4. Early heat stress in Dhar and terminal heat stress in Mewat affected the crop growth and grain filling, and ultimately the yield of wheat crop.
5. The vegetable crops being affected due to frost.
6. Adaptation to these climatic risks and stresses is a challenge to the farmers as they are already plagued by the non-climatic risks such as
   - i. Poor water quality and irrigation facilities,
   - ii. Low market return of agricultural produce,
   - iii. Increasing cost of inputs,
   - iv. Poor supply of electricity,
   - v. Incidence of insect pests and diseases in crops,
   - vi. Lack of technological know-how,
   - vii. Unavailability of quality seeds and planting materials,
   - viii. Lack of collective action,
   - ix. Lack of marketing facilities,

x. Lack of animal health care facilities,

xi. Lack of human health care facilities,

xii. Lack of credit facilities,

xiii. Tenancy constraints and

xiv. Undulation of land and problem soils.

As it is believed that the readiness of the farmers towards adaptation will be more effective if they perceive the risks associated with climate change as a major threat to their livelihood, an attempt was made to assess the perception of the farmers about climate change.

Farmers' perception about climate change

About 43 per cent of them perceived the climate change as a reality (Fig. 44). It is a positive and encouraging reflectance of the farmers' perception as far as adaptation is concerned. They would take corrective measures to offset the risks. However, the perception based upon metaphysical explanation about the climate change phenomenon like curse of god, could retard the adaptation initiative among the people. Similarly, the perceptions like climate change being a hoax, a pessimistic outlook of people, a temporary phenomenon, and a nature's revenge could also retard the readiness towards adaptation.

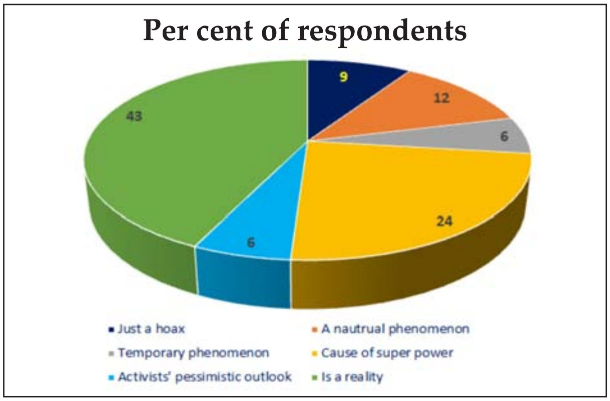


Fig. 44: Farmers' perception about climate change in Mewat district.

Characterizing agriculture in Mewat and Dhar from climatic risk view

The farming community in both districts have been facing different types of climatic stresses and have been following adaptation methods. But even these category of farmers are very less. Among the sample of farmers those have been already implementing adaptation technologies such as change of variety, agronomic adjustment, multiple cropping apart from non-farm activities and crop diversification (Table 9).

Table 9. Different adaptation options used by the farmers

S. No.	Adaptation option	Frequency	Percentage
1.	Change of variety	97	27.7
2.	Multiple cropping	82	23.4
3.	Agronomic adjustments	86	24.6
4.	Crop diversification	37	10.6
5.	Non-farm activities	48	13.7

As kharif season is more critical due to vagaries of monsoon, drought, high temperature and hot winds, the farmers deployed different adaptation strategies in order to sustain livelihoods. About 28 per cent of the farmers reported using short duration varieties of pearl millet in the event of delayed monsoon. Nearly 23 per cent of farmers practiced multiple cropping like growing sesame, pigeon pea, maize, besides the main crop of pearl millet. Nearly one-fourth of the farmers adopted agronomic adjustments like early or delayed sowing, reducing the fertilizer dosages, increasing the frequency of irrigation. In addition, reducing the area under cultivation and leaving land fallow was also practiced. As the farmers realized that problem of grain filling in wheat was due to rise in temperature during terminal stage of crop growth, they started early sowing of wheat. Further, crop diversification, one the major options in planned adaptation interventions by public or private organizations, is followed by about 10 per cent of the farmers, while non-farm activities are adopted by about 13 per cent of the households. From the above it is evident that farmers have been trying to adapt to climatic risks but their number is very low. Even those adaptation options are very limited and not comprehensive.

Determinants of farmers' adaptation behavior

Adaptation is not a pervasive phenomenon among the farmers. Studies to delineate reasons for wide-variation in farmers' adaptation behavior identified household characteristics, farm characteristics, institutional support, etc as the factors that explained the adaptation behavior. Both psychological barriers and behavioral adjustments to adaptation have been reported. Adopting soil and water conservation practices, applying optimal number of irrigation, altering the cropping pattern, change of varieties and altering planting time (Mengistu, 2011); reduction of farm inputs, mixed farming and diversification (Obayelu *et al*., 2014); market exchanges (Smit *et al*.,

2000) and extension of social network (Adger,2003) are some of the manifestation of adaptation at farm level.

Multinomial logistic regression analysis was used to explain the adaptation behavior determinants. It is evident that the factors like level of education, risk perception, access to irrigation, access to credit, linkage with market, social network, social participation, risk taking willingness, extension contact, mass media exposure and size of holding were influential for adaptation behavior among the farmers (Table 10 and 11).

Table 10: Parameter estimates of the multinomial logit model for adaptation behavior.

Explanatory variable	Change of variety	Multiple cropping	Agronomic adjustments	Crop diversification
	Coefficients	Coefficients	Coefficients	Coefficients
Intercept	-20.0***	-15.6***	-27.1***	-39.2***
Education	2.22***	0.469	2.27***	3.02***
Linkage with market	0.39	1.99**	4.23***	3.24***
Risk perception	1.39***	1.21***	1.61***	1.49***
Access to credit	-0.31	-0.74	0.42	2.47***
Access to irrigation	0.71	-0.03	1.246*	3.51***
Size of holding	.413*	.878***	.146	-.138
Extension contact	1.659	4.225	6.683**	2.476
Social participation	1.548***	1.214***	1.132**	1.347***
Risk orientation	6.130***	5.166***	7.203***	10.615***
Mass media exposure	-.036	.459	6.576**	7.83**
Experience in farming	-.004	-.034	.007	.025
Social network	7.462***	3.458*	2.643	6.532**
Size of family	-.037	-.120	-.188	-.134
Family type				
[famtyp=1.00]	.616	1.773	-2.465*	-1.122
[famtyp=2.00]	1.181	1.718	-.756	.076
[famtyp=2.00]	0^b	0^b	0^b	0^b

Base category: Non-farm
Likelihood ratio chi square (60): 444.9
-2 Log Likelihood : 640.4
Prob> chi square: 0.000
Pseudo R^2 Nagelkerke: 0.75
Level of significance: ***1%; ** 5%, and * 10%

Table 11. The marginal effects of the determinants of climate change adaptation.

Explanatory variable	Change of variety	Multiple cropping	Agronomic adjustments	Crop diversification
	Coefficients	Coefficients	Coefficients	Coefficients
Intercept	-0.07696***	-0.0175***	-6.4294***	-1.8457***
Education	0.0085***	0.0005	0.538***	0.1422***
Linkage with market	0.00153	0.0022**	1.0029***	0.1527***
Risk perception	0.0053***	0.0014***	0.3826***	0.0700***
Credit	-0.0012	-0.0008	0.0996	0.1163***
Access to irrigation	0.0027	-4.02803E-05	0.2956*	0.1651***
Size of holding	0.00159*	0.001***	0.0346	0.0109
Extension contact	0.0064	0.0047	1.5853**	0.1166
Social participation	0.00595***	0.0014***	0.2685**	0.0634***
Risk orientation	0.0236***	0.0058***	1.7086***	0.4998***
Mass media exposure	-0.00014	0.0005	1.5599**	0.3686**
Experience in farming	-1.53728E-05	-3.80425E-05	0.0017	0.0012
Social network	0.0287***	0.0039*	0.62695	0.3075**
Size of family	-0.00014	-0.0001	-0.0446	-0.006
Family type				
[famtyp=1.00]	0.00237	0.002	-0.5847	-0.052825517
[famtyp=2.00]	0.00454	0.002	-0.1793	0.003578199

Level of significance: *** 1%; ** 5%, and * 10%

Strategy for Adaptation to Climate Change

Based upon the identified factors which could enhance adaptation process, as obtained from multinominal regression analysis, a strategy was devised to facilitate the adaptation among the vulnerable communities in Mewat and Dhar. Emphasis was laid on capacity building of the farmers, farm women and rural youth apart from technological backstopping. A 5-C model of adaptation with elements of Capacitation, Collectivization, Collaboration, and Collation was conceptualized and operationalized. Autonomous adaptation becomes challenging due to several factors like attitudinal disposition, resource endowments, services, etc. Therefore, a planned intervention for promoting adaptation needs to be contemplated. Adaptation could involve both building the adaptive capacity to increase the ability of individuals to adapt to changes as well as transforming the capacities into actions (Adger *et al.* 2005). In this project, holistic approach for adaptation was deployed through capacity building, technological and institutional fortification, resource support system, handholding and linkages.

Adaptation framework for livelihood resilient to climatic risks

As mentioned above, the selected districts are prone to climatic risks and these risks are projected to increase in future climates with significant effects on livelihoods of the people. Therefore, the project dealt with the livelihood security of the rural communities through adaptation to climatic risks. As these are primarily agrarian communities, multi-dimensional interventions were based on 1) crops and their management, 2) change in crop varieties, 3) crop diversification, 4) livestock and fodder management, 5) value addition, 6) developing/improving secondary skills, 7) improving the individual and community natural resource management 8) improving the line-department and local institutional linkage 9) improving awareness and 'know-how' on various aspects of agriculture 10) improving 'do-how' on crop and natural resource management 11) knowledge empowerment of the farmer through information, 12) set up of the village resource centres for knowledge and hard-ware support 13) establishing the seed villages 14) enhancing the horticultural and plantation activities and 15) development of human resource at village level for sustaining the intervention impacts. Convergence of all or many of these are aimed to minimize the climatic risks.

A 'participatory adaptation strategy' was developed based on scientific analysis as well as systematic involvement of rural communities and other stakeholders (Fig 45) to implement above mentioned adaptation activities. In scientific analysis, apart from the analysis of climatic data for past and projected climatic conditions, their impact on crops as well as potential adaptation gains were done using the simulation models. Impacts and gains due to potential adaptation options to climate change were simulated using the InfoCrop, a crop simulation model with the climate data inputs from PRECIS, a regional climate model (RCM). Adaptation to climate change has two components 1) adaptation to mean climatic change and 2) adaptation to immediate short-term weather stresses. The potential adaptation options such as change in variety and improved input use efficiency through resource management were tested in

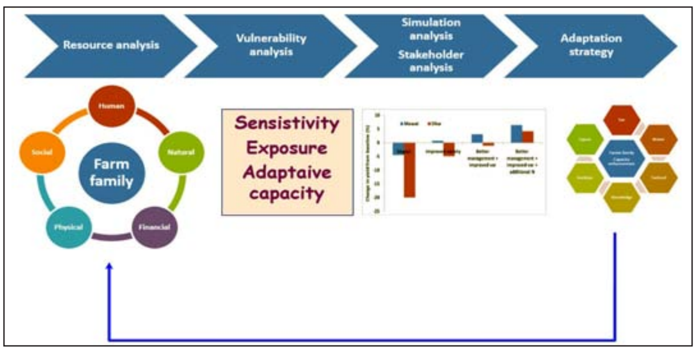


Fig. 45: The framework for development of participatory adaptation strategy in the climatically challenged areas.

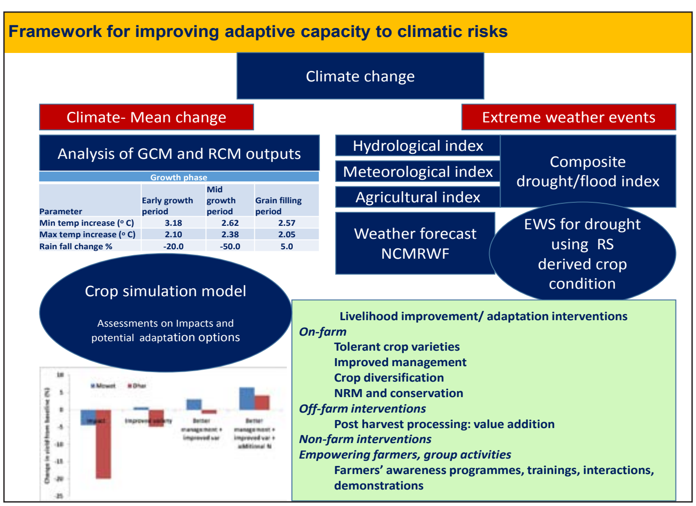


Fig. 46: Detailed framework of the improving the adaptive capacity of the rural communities to the climatic risks.

simulation analysis and selected interventions were implemented in the project area. The short-term climatic risks such as droughts, floods and extreme temperature events were managed using the weather forecast, and by providing management options and contingency plans.

The adaptation strategy framework (Fig 45 and Fig 46) that was followed has been a holistic and integrated for ensuring the resilience of livelihood to climatic risks. As mentioned earlier, to reduce the climatic risks in the study areas, a multi-pronged strategy was developed and implemented not only for crops but also for livestock, other on-farm, off-farm as well as non-farm interventions.

To identify suitable adaptation interventions for major crops viz., wheat, mustard, soybean and maize in Mewat and Dhar, as well as for rice in Ganjam and Raigad, a simulation analysis was carried out for respective districts. For this InfoCrop, a generic crop model developed at the Division of Environmental Sciences (currently Centre for Environment Science and Climate Resilient Agriculture), Indian Agricultural Research Institute, New Delhi was used. This model was first released in 2006 (Aggarwal et al., 2006) and was subsequently updated (Naresh Kumar et al., 2014). The updated models were used for this analysis. For simulation of impacts, data on soil, weather of past 30 years, climate scenarios, varietal coefficients and crop management details such as sowing time, organic matter, nitrogen and irrigation amount and application etc. were used. For simulating the adaptation options, all combinations were developed using above parameters with alternative varieties and agronomic management with past as well projected climatic conditions. This provided an array of adaptation options.

Details about the InfoCrop model and simulation setup

Simulation analysis using InfoCrop

InfoCrop- wheat, mustard, soybean, maize and rice models were used because of their suitability for simulating the growth, development and yield of these crops in sub-tropical and tropical conditions such as in India. InfoCrop can simulate the effects of weather, soil, agronomic managements (planting, nitrogen, residue and irrigation), and major pests on crop growth and yield (Aggarwal et al., 2006). The model dynamically simulates different growth and development processes of a crop. The total crop growth period in the model is divided into three phases: sowing to seedling emergence, seedling emergence to anthesis and the storage organ filling phase. The model requires various coefficients such as thermal time for phenological stages, potential grain weight, specific leaf area, light extinction coefficient, maximum relative growth rate and maximum radiation use efficiency.

Crop management inputs include time of sowing, seed rate; application schedule, and the amount and type of organics, fertilizer and irrigation. Soil input data include pH, texture, layer-wise thickness, bulk density, saturated hydraulic conductivity, organic carbon, slope, water holding capacity and permanent wilting point. Location-wise daily weather data (solar radiation, maximum and minimum temperatures, rainfall, wind speed and vapour pressure) are also required to simulate the crop performance. The details on simulation framework of temperature, CO_2, and rainfall effects on crop growth and development are described in several research papers (Aggarwal et al., 2006; Srivastava et al., 2010; Byjesh et al., 2010; Naresh Kumar et al., 2011, 2012, 2013, 2014).

The InfoCrop-WHEAT model was calibrated and verified for Indian varieties (Aggarwal and Kalra 1994, Aggarwal 2003, Aggarwal et al., 2006, Aggrawal and Swaroopa Rani 2009). The model could capture the year-to-year variation in dry matter (root-mean-squared error –RMSE=0.55 t ha^{-1}, mean=9.9 t ha^{-1}) and grain yield (RMSE=0.21 t ha^{-1}, mean=4.7 t ha^{-1}) of experiments (Aggarwal et al., 2006). The model performance indicators such as RMSE, model efficiency (ME), agreement index (IA) and bias (Wallach et al., 2013) indicate that the model could simulate the phenology and grain yield of different varieties sown in timely-, late- and very late-conditions as well as in different locations (Naresh Kumar et al., 2014). Similarly the InfoCriop-RICE (Mall and Aggarwal, 2002; Naresh Kumar et al., 2011, 2013), InfoCrop-MAIZE (Byzesh et al., 2010), InfoCrop-MUSATRD (Bhoomiraj et al., 2010) and InfoCrop-SOYBEAN (Naresh Kumar et al., 2012; Bhatia et al., 2014) were calibrated and verified for several leading varieties in India. These calibrated and verified models were used for simulating the yield to assess the impact, adaptation gains and net vulnerability of crops in the study districts.

Details about the model inputs data

Weather: The India Meteorological Department (IMD) supplied daily gridded data on rainfall, and minimum and maximum temperatures. Based on the availability of observed weather data, 1969-1990 period data coinciding with the baseline period (1960-1990) of climate models was used. These data were converted to InfoCrop weather file format using custom made software. Files for 22 years (1969-1990) for each grid were prepared. This data served as the observed data for baseline period. Solar radiation was calculated based on the Hargreaves method (Hargreaves, 1994), which is reported to be the best suited for Indian conditions (Bandyopadhyay et al., 2008). The potential evapotranspiration was calculated by the Priestley and Taylor method. Apart from the gridded data, the point data (where ever available) were also used.

Soil data: Data on soil parameters such as texture, water holding characteristics, bulk density, soil pH, and depth of three soil layers were adopted from the soil database of National Bureau of Soil Science and Land Use Planning (NBSSLUP), India and Harmonized World Soil Database – HWSD v1.1 (FAO, International Institute for Applied Systems Analysis –IIASA, World Soil Information – ISRIC, Institute of Soil Science – Chinese Academy of Sciences – ISSCAS, Joint Research Centre of the European Commission –JRC 2009). The HWSD v1.1 is a 30" raster database with more than 15000 different soil mapping units containing information within the 1:5,000,000 scale world soil map. The NBSSLUP data base is at 1:250,000 scale providing soil series information for 60 agro-eco sub-regions of India. The characteristic data of major soil type in a grid were extracted using GIS tools and input into the model. The pedo-transfer functions were used to derive the hydraulic characteristic coefficients.

Varietal coefficients: The coefficients of dominant varieties of wheat, mustard, soybean, maize and rice in respective districts were used. Grids covering a region with similar type of dominant cultivars had similar varietal coefficients. The performance of short-, medium- and long-duration varieties sown in timely-, late- and very late-conditions, respectively, was simulated and the combination that gave the highest grain yield was taken for the baseline and for impact assessment.

Management: In order to mimic the situation in farmers' field conditions, the crop specific management was provided with variable doses and application schedule of fertilizers, irrigation and organics. Since understanding on the crop-pest interaction in future climates is not well established, crop is assumed to be maintained free of pest and disease infestation so as to delineate the effect of climatic parameters on crop performance.

Estimating impact of climate change

Estimating baseline yields: Simulations were run for each of the sowing times for 21/22 years (sowings in 1969-1989 and harvests in 1970-1990 for wheat and mustard; 22 years for other crops) using the IMD gridded data as well as the point data. Yields of all the 21/ 22 years were averaged grid-wise. District-wise yield was obtained as a sum of the weighted yield from each grid fraction in the district. This was the baseline yield of a district for the respective sowing condition.

Simulating yields in future scenarios: For simulating the impact of climate change on crop yield, the climate outputs of a regional climate model (RCM, PRECIS—Providing Regional Climates for Impact Studies—which had the Hadley Centre Climate Model-HadCM3- as the GCM) were used. They are found to suitably simulate Indian climatic conditions (Rupa Kumar et al., 2006, Das et al., 2012) and the PRECIS is extensively used in climate change studies in India (INCCA 2010, NATCOM 2012) for A1B 2030 scenario. Climate scenarios were derived using the climate model projected changes in monthly temperatures (minimum and maximum) and rainfall for 2030 scenario following the method given in Naresh Kumar et al., 2011. A major advantage of this method is that it overcomes the bias of the climate model for baseline weather. The carbon dioxide level (522 µmol/mol air) for this scenario was also included in the crop model for simulations. All other simulation conditions were maintained as explained earlier. Based on the simulated yield in future scenario, district yield was calculated as in the case of baseline yield assuming that the area under crop would remain the same in the future as well.

Simulating adaptation gains in future scenarios

Several low-cost and easy-to-adopt adaptation options were tested independently, or in combination, to assess the adaptive capacity of wheat crop to climate change. These strategies included a) use of improved variety (short-, medium- and long-duration varieties with high temperature stress tolerance), b) change in sowing time – advanced or delayed by one week for late- and very late- sowing window, advanced or delayed by ten days for current optimal sowing window; c) rescheduling irrigation-application time to suit the phenological stages in future climate, and extra split application of nitrogen (i.e., three splits for wheat and rice, and three equal splits for maize) with-, and d) without 25% additional nitrogen (except for soybean). Similarly, improved application method of irrigation water was also simulated. The combination which gave the highest yield in each grid was taken as the best suitable adaptation option. The yield deviation from mean baseline yield was expressed as per the equation given in Naresh Kumar et al., 2011, 2013, 2014). In all, about 3 million simulations were carried out for this entire analysis.

Projected impacts on crop yield and adaptation gains

Summary of results for wheat, rice, maize, mustard and soybean indicate that climate change may reduce the crop yield in most of the places in these districts. Simple but critical changes in crop management as well as growing improved varieties not only can offset the negative impacts but also significantly improve the yields. For instance, wheat yields can be improved with change in variety which is of short-duration and with temperature tolerance. Change in sowing time is found to be an important and most significant crop management option for improving wheat yield. Combining these with better management (timely application of nitrogen and irrigation) can significantly improve the yields in Mewat and Dhar districts (Fig 47). On the other hand in Ganjam, rice yields are projected to improve due to change in rainfall amount in future climates. This positive influence can be further enhanced by improved agronomic management

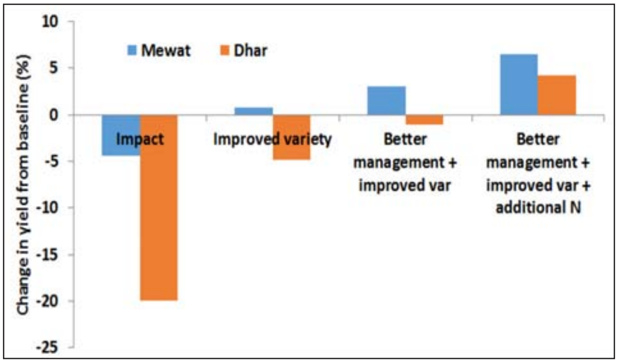


Fig. 47: Simulated impacts on wheat yield and adaptation gains in 2030 scenario in Mewat and Dhar districts.

in this region (Fig 48). Like wheat, yields of maize in Dhar and Ganjam are projected to be reduced in future climate if current varieties and management are followed (Fig 49). With change in variety and management, however, yields can be improved.

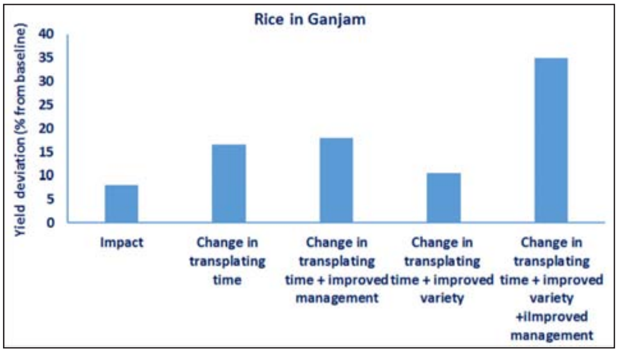


Fig. 48: Simulated impacts on rice yield and adaptation gains in 2030 scenario in Ganjam district.

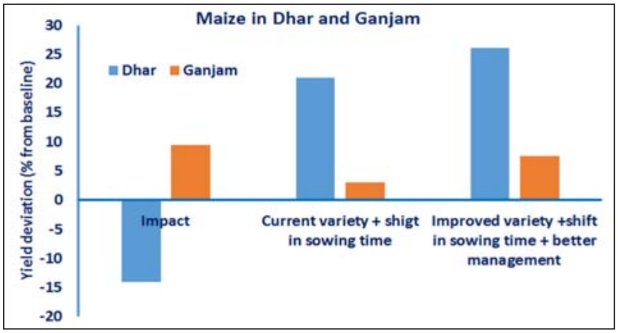


Fig. 49: Simulated impacts on maize yield and adaptation gains in 2030 scenario in Dhar and Ganjam districts.

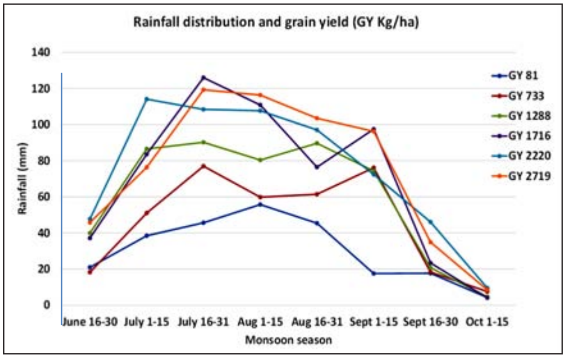


Fig. 50: Simulated impacts of seasonal rainfall and its distribution on soybean yield in Dhar.

In central India, soybean has emerged as the major crop during kharif season. However, the crop performance is strongly correlated to the rainfall amount and distribution. Analysis indicated that any deviation from optimal rainfall distribution significantly reduced yield even though total amount of rainfall remained same (Fig 50). High rainfall coinciding flowering and pod maturation was found to affect the yield severely.

Simulating wheat yield in farmers' fields differing in crop management and simulating the performance of short duration heat tolerant variety

Since crop management significantly varies in a village even for a single crop, simulation analysis was also carried out for knowing impacts on farmers' varieties with different levels of management that were followed in the project area. To capture the variability in the potential impacts of climate change and adaptation gains in different farms in villages, 2000 different management combinations along with varietal variations were input into the model for simulating the impact of climate change on wheat, a major crop in Mewat and Dhar district. This analysis was done for Mewat district. For this analysis, following inputs were used in the model:

Weather: Block-wise daily weather data of past 30 years were used for this analysis.

Soil data: Data on soil parameters such as texture, water holding characteristics, bulk density, soil pH, and depth of three soil layers were adopted from the soil database of National Bureau of Soil Science and Land Use Planning (NBSSLUP) India. The pedo-transfer functions were used to derive the hydraulic characteristic coefficients.

Varietal coefficients: The coefficients of dominant wheat varieties in the study area were taken. Farmers have been growing the wheat varieties such as PBW 343 and WH

711. The improved varieties included HD2967, WR 544, HD 2851, HD 2985, HD 2824 among others.

Management: In order to mimic the situation in farmers' field conditions, crop was provided with variable doses of fertilizers, organic matter as well as the irrigation, based on the survey data. Similarly, seed rate and time of sowing were also varied. All these parameters for each of the 2000 farmers were input into the model. Sowing time varied from November first fortnight to December 2nd fortnight. Seed rate varied from 100-180 kg/ha while irrigation varied from 3- 8 irrigations. Application of organic matter ranged from 0 kg/ha to 10,000 kg/ha. Similarly nitrogen dose varied from 30 Kg N/ha to 150- kg N/ha. Half of the nitrogen was applied as urea at the time of sowing and remaining half at crown root initiation-CRI (20-25 days after sowing) stage. Irrigations (50 mm each) ware provided at the CRI, jointing, flowering, milk and late grain-filling stages of crop apart from a pre-sowing irrigation. Two additional irrigations were also given as practiced by some farmers. These irrigations were given during the grain filling period. Crop is assumed to be maintained free of pest and disease infestation to delineate only the weather effects. All these were input into the model.

Simulating adaptation gains in future scenarios: Analysis of climate projections indicated that in future not only mean temperatures increase but also heat-stress will coincide with sensitive stages of crop growth such as early growth, flowering and grain filling period, particularly in winter season. Several low-cost and easy-to-adopt adaptation options (as mentioned earlier) were tested independently or in combination, to assess the adaptive capacity of wheat crop to climate change. In all, about 1.5 million simulations were carried out for this entire analysis.

The analysis indicated that wheat yield significantly decreased when growing season mean maximum and minimum temperatures increased from 28.4 to 29.7°C and from 13.6 to 16 °C, respectively (Fig 51). In this scenario, temperature stress seems to be predominating the management in determining yield variations. Thus, high yielding farms may stand big losers than low yielding farms due to temperature stress. However, by changing sowing time and adopting a short duration variety, the crop was exposed to seasonal mean maximum and minimum temperatures in the range of 26.7-28.4 °C and 11.4-12.5 °C, respectively. In this case, variability in yield due to management has predominated the temperature effects. Better managed farms gain more than the poorly managed farms. Thus this analysis highlights the importance of changing variety, change in sowing time as well as improved management. Similar analysis was done for soybean with reference to change in rainfall as well as for

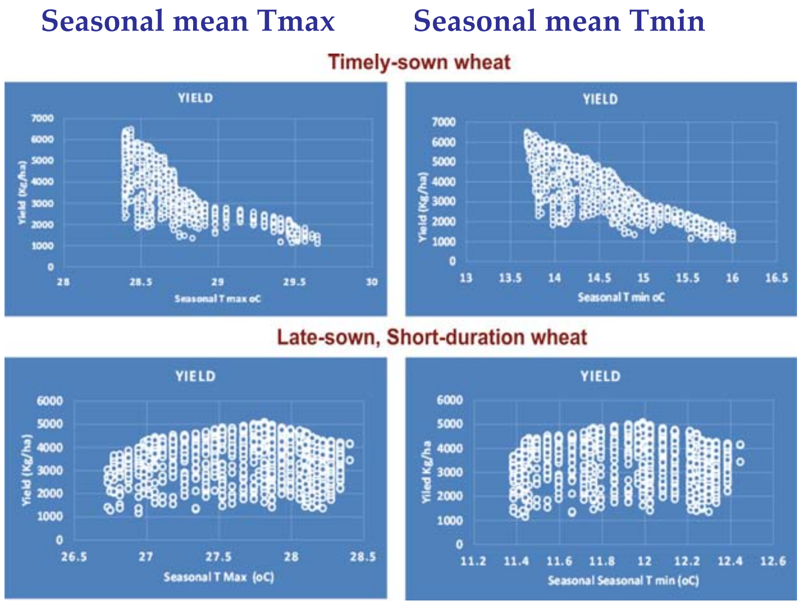


Fig. 51: Simulated impacts of seasonal temperature on wheat yield and adaptation gains for Mewat farmers (2000 farmers wheat management situations were simulated). Upper panes show the effect of high seasonal mean maximum and minimum temperatures on yields of timely sown long duration wheat varieties. The lower panes show grain yield as a result of growing short duration variety with change in sowing time. Variations in yield levels in the lower panes are due to differences in crop management.

other crops. These studies imply that climatic stress impacts can be minimized by replacing the currently grown varieties with suitable tolerant varieties in the farmers' fields. Further, agronomic adaptation like shifting sowing time, water management and fertilizer management can help in improving the yields substantially. Based in these analyses several new verities along with combination of crop management interventions were planned to be implemented in the villages.

Interventions Implemented to Minimize Climatic Risks and to Enhance Livelihood Security

The project intervention design emphasized upon:

- Sensitization and awareness creation about climatic risks and mobilizing for community initiatives for adaptation
- Strengthening of adaptive capacity through capacity building interventions
- Testing, modifying and demonstrating innovative technologies for crop management and diversification, water harvesting and on-farm soil and water management
- Promotion of profitable livestock and fishery management
- Capacitating for community monitoring, evaluation and impact assessment of innovations introduced by the project
- Promoting institutional mechanism for sustainability

Phase I -Conceptualization phase: Based upon the climatic risks analysis, community need and participatory problem analysis, an action plan was developed and ratified by the community. Efforts were made to integrate adaptation throughout project area and in collaboration with community organizations, village residents, community leaders and village-headman. Community initiatives provided impetus to local adaptive capacity and resilience to climate change.

Traditionally farmers focused upon existing risks and coping strategies were based upon recent past and current evidence. The new strategies in climate change adaptation must consider both the long term historic climate information along with future climate scenario to incorporate all possible risk-in agriculture. Therefore, necessary attention on all risk reduction initiatives such as adaptation and mitigation (climate resilient agriculture) needs to be paid in agricultural research and development planning. Adaptation in livelihoods sector is dependent not only on components that are directly related to climate change but also on other non-climatic components (NCC) such as economic conditions, technology associated with NCC, socio-economic and socio-political environment, etc. Adaptation is now accepted and recognized as an important component of climate change response strategy. Exploring adaptation options in several sectors leading to livelihoods security of the people is emphasized upon. For example, at the community level, strategies include improvements to agricultural systems through intervention of components (either single, or in combination – need based), such as introduction of resistant crop(s) varieties; crop diversification; development or rejuvenation of water resources, enhanced use efficiency of resources, reassessments of risk, contingency plan preparation; early warning systems; increase in awareness process and capacity building of the stakeholders.

Phase II: Execution of interventions phase: The second phase included execution of identified NGO partners of respective cooperating centers by providing necessary technical and other support, and increased interaction as well as confidence building within stakeholders and follow through hand-holding during the whole project period.

The project team was already working on understanding of bio-physical and socio-economic data collection, climate data analysis for project areas, interaction with the stakeholders, reconnaissance etc. Outreach research and field demonstration work was initiated at smaller scale through identification of proven technologies/techniques that were feasible, environmentally sustainable and economically successful either at experimental farm or elsewhere (with similar agroecological and socio-economic context), but neither tested or widely known to the beneficiaries of the targeted project areas. A regular farmers-stakeholders and project personnel interaction meeting was organized to focusing on options to share the project work plan, necessary modification done based on local experiences, need of the people, prioritized urgency of intervention and feedback. This strategy promoted by the project had gained people's confidence and cooperation in very short-time.

Under this project, maximum concentration was inclined towards interventions. A blend of area-based and family-based interventions have been achieved in the catchments with clusters. The community owned resources had been developed and managed through local level institutions and/or CBOs. Local level organizations for each cluster had been promoted. A basket of interventions such as, improved agriculture (INM, IPM, improved seed, crop diversification), and vegetable cultivations had been introduced in project area. Based on land, livestock and human resources with a family, the group interventions had been adopted. The intervention through integrated farming approach like backyard poultry, goat keeping, beekeeping, etc had been also introduced to increase the per capita income and economic status of the farmers.

The seed village concept and availability of quality planting materials had been implemented to address the important issue of availability of basic inputs. Low milk production of the livestock is also a major constraint in all districts. Hence, an intervention of animal health management is included. Villagers were supported with the technologies viz. animal feeding, timely vaccination, preventions of minor diseases and animal care etc. to increase animal productivity in the area. Interventions of management of natural resources viz. soil, water, biodiversity etc. had facilitated the availability of water for additional cropping and thereby for economic gains.

Apart from the above major activities, attempts were made to establish various drought indices including remote sensing based indices for the project districts in order to facilitate need based early warning System for drought region. Baseline survey, ITK analysis, and working with expert and PRA/RRA/focus group discussion on identification of lag period in forecast products needs had been prepared.

Phase III: Strengthening of linkages for sustainable adaptation: In third phase, strengthening of linkages with cooperating centers and NGOs was developed for ensuring the sustainability. Exit plan and handing over the assets and resources developed as well material and goods to the community was formalized.

To reduce the adverse impacts of climate change as described in earlier sections, several adaptation interventions were implemented in about 50 villages in four districts on various aspects. Farm based interventions formed the bulk of interventions. Adaptation interventions were undertaken among more than 5000 farmers (covering 2600 ha). The project enabled tangible economic development of farmers through agriculture, animal husbandry, fisheries and livelihoods interventions, and overall development of the local communities in general. Some major interventions are briefly mentioned below (Table 12).

Table 12: List of implemented interventions for minimizing climatic risks and enhancing livelihood security.

Type of intervention	Description	Relevance to climatic stress and livelihood security
Crop varieties	Heat and drought tolerant varieties and short duration varieties of pearl millet, pigeon pea, etc.	To overcome/avoid terminal heat stress in wheat, drought/ heat stress in monsoon crops
	Multi-cut fodder sorghum variety	Heat and drought tolerant varieties; increased fodder for livestock
Crop diversification	Maize in place of pigeon pea	Being a C4 crop can withstand higher temperatures; increased income
	Short duration vegetable crops	To fit in cropping sequence window; increased income

Cropping pattern	Fallow-early mustard-wheat/ vegetables	To minimize loss due to crop failure during uneven and delayed monsoon
Water saving technologies	Laser levelling Sprinkler Rain gun Drip irrigation Underground pipeline for water conveyance Soil moisture conservation (mulching) in vegetable crops	Reduced water loss; increased water use efficiency by over 50%; 450-650 m^3 water saved; 20% additional area under irrigation with same amount of water; reduced emission of 65-120 kg CO_2/ha.
Crop management	Improved seeds, timely sowing	Reduced in-breeding loss Avoid terminal heat stress in wheat; avoid water stress in monsoon crops
	Recommended sowing rate	Avoid inter-plant competition and lodging due to heavy winds
	Timely and recommended irrigation	Improve water use efficiency and reduce diesel/ electricity for pumping water; reduce GHG emissions
	Recommended fertilizers	Avoid excess fertilizer application; reduce GHG emissions
	Pest management	Pheromone traps –ecofriendly; reduce pesticide load and GHG emission
	Shade nets	Disease free nursery of horticultural crops for main- and off-season; improved income
Horticultural and fruit plants	Back-yard horticultural and fruit plants such as guava, sapota, pomegranate, papaya, etc.	Carbon sequestration; nutritional security
Livestock	Increased availability of fodder and feed	Improved fodder led to increase in milk yield (1.5-2 L/animal/day)
	Regular health checkup; immunization; mineral nutrient mix supplement	Reduced calf mortality from 70% to 20%; improved the health of livestock; increased climatic risk coping ability due to availability of more number of male calves for distress or other-wise selling, improved income insurance in stress conditions
Value addition	Wheat flour making Grading of tomato Pickle making Dhal-dhalia making	Improved income for farm produce
Secondary skill development	Tailoring, mushroom culture, poultry, etc.	Income augmentation
Information and weather-forewarning	m-Krishi mobile based information system on weather, crop management, market and training	Weather-based crop management; information on markets, training, etc.; enabled farmers with information on climatic risk management.








Details of Interventions

1. Integrated crop management

- Replacement of local wheat seed with early heat and drought tolerant varieties in parts of Dhar (Madhya Pradesh). To reduce crop loss due to temperature stress, heat and drought tolerant wheat varieties viz. HI 1500 (Amrita), HI 1531 (Harshita), HI 1544 (Purna) and HI 8627 (Malav Kriti) were introduced.
- Introduced varieties tolerant to terminal heat stress in wheat in Mewat District included WR 544, a variety suitable for irrigated late and very late sown conditions. This variety possesses terminal heat tolerance. The other suitable varieties are HD 2824, HD 2932 and HD 2985 as well as high yielding and long duration variety HD 2967.
- Integrated Crop Management (ICM) in rice enhanced the crop productivity across lowland ecology of Ganjam in Odisha.
- Introduction of improved maize hybrid HQPM1.
- Introduction of high yielding and short duration soy bean varieties (JS 9560 and JS 9305) as well as high yielding and long duration variety JS 9752.
- In order to avoid the possible terminal moisture stress/ drought situation in uplands, short duration (~100 days duration) rice varieties viz., Anjali, Annada and Sahabhagidhan were introduced during wet season (July- December).
- In semi-deep and deep water ecologies, ICM module developed by CRRI i.e. HYV (Varshadhan, Durga, Sarala), line seeding, integrated nutrient management (FYM, 5t/ha +NPK 40:20:20 kg/ha), mechanical weeding and need based plant protection was tested

2. Crop diversification

- Integration of moong bean (cv. SML 668 & Pusa Vishal) cultivation in cropping system in Mewat.
- Crop diversification with vegetable crops
- Use of pheromone traps in tomato helped to reduce the pesticide use by 3 to 4 applications,
- Grading of tomatoes
- High yielding varieties of Chilli (Utkal Rasmi), Brinjal (Utkal Keshari), Tomato (Utkal Kumari) and Onion (N 53) were introduced during dry season (January–April).

- To exploit the residual soil moisture as well as the availability of additional water in the water harvesting structures during the rabi season, ground nut (TMV 2) and sunflower (KBSH 1) were taken up with improved management practices.

3. Shade net and polyhouses for raising vegetable nursery

- In Mewat and Dhar districts, 56 net houses of 100 m^2 were constructed to raise quality and pest free nursery of vegetable crops.

4. Seed production

- Eleven seed villages were developed in tribal district of Dhar. Breeder seeds of crops were used for field trials for good quality seed production. Farmers were trained on raising and monitoring of crop for seed production.

5. Integrated water management

- In Mewat region, integrated water system interventions included laser leveling, underground pipeline system and sprinkler irrigation/ rain gun to save irrigation water through increase in conveyance and application efficiency.
- In tribal dominated Dhar district, water resource sharing by forming small water user groups (3-7 household); common under-ground pipeline for carrying water from source to respective field clusters; sharing sprinkler /rain gun /drip irrigation sets to reducing water consumption, ensure equity in sharing of scarce resources; rainwater harvesting and groundwater management based on social regulation schemes.
- Development/ renovation of village tanks, existing water harvesting systems, developing water harvesting structures, deepening open wells in Dhar district.

6. Animal based technologies for livelihood support

- Livestock provides resilience to the farmer in the periods of distress. Livestock is one of the major components of livelihood in Mewat region. However, calf mortality, poor health of cattle and low milk yield have been the grave concerns. A multipronged approach comprising of immunization, nutrient supplements, availability of additional fodder and feed was implemented to increase the profitability through increased milk yield, income and also to improve the health of children of farming families.
- Introduction of improved varieties of wheat that gave higher yield of wheat straw along with the grain yield to improve the feed availability to the cattle.
- Introduction of multi-cut fodder sorghum concurrently to make the area self-reliant with respect to the fodder requirement.

7. Pusa mKRISHI based mobile advisory service

- In this project, weather and climate information played an important role in its successful implementation of community based adaptation initiatives in project districts.
- Community access to weather and climate information was enabled through Pusa mKRISHI, a mobile based technology. This is a two-way interactive system in a way that there is no additional load on the existing agro-extension system but still givs "Any Time Query (ATQ)" support.
- Wth mKRISHI®FISHERIES, the fishermen of coastal areas of Raigad in Maharashtra could make targeted catch of fish.

8. Alternate income sources from non-farm based technologies and value addition

- Training rural women on tailoring, pickle making, spice powder making, preparation of daal, dalia and chilli powder, cultivation of mushrooms, apiculture to strengthen farm house livelihood security.

9. Village Resource Centres

- Establishing Village / Rural Resource Centres to facilitate sharing of information and services such as custom hired service facilities of farm implements and equipments for value addition.
- The farmers had access to equipments as well as information through notice board, internet and TV connectivity.
- Development of sustainability fund.

Analysis on the Performance of Introduced New Varieties and Technologies

Based on the analysis of impacts and potential adaptation strategies, multi-pronged strategies such as introduction of improved varieties, change in sowing time as well as improved water and nutrient management were implemented systematically in the project villages. The improved varieties and other management options to be implemented were selected based on the simulation analysis. The farmers in selected villages were using local varieties which have under gone several cycles of inbreeding and, thus were low yielding due to inbreeding depression. Initially, a compendium of improved varieties, based on the suitability with regard to the crop duration and time of sowing were introduced in the farmers' fields. Five new varieties were grown in about 300 farm fields for each crop in small strips along with large area under the varieties that have been already in cultivation. The new varieties of crops such as wheat, mustard, gram, soybean, maize, pearl millet, fodder sorghum, red gram as well as those of vegetables were introduced in several villages of two districts viz. Mewat and Dhar.

During the first year, yields from different varieties were compared by the farmers as well as by the project team by taking the samples from $1m^2$ area in about 300 farm fields. Further, seeds were harvested separately for each variety and were used for developing the seed bank in each village. These seeds as well as those supplied by the project team in subsequent years were sown in more than 600 farm fields in Mewat and Dhar, respectively for each crop. The seed developed in farmers' fields were used not only by themselves but also have been distributed to others through farmer-farmer interaction. Some of the farmers have sold the seed to get substantial additional income. In the following sections, the performance and the impact of introduction of new varieties on the overall yield levels are presented for major crops such as wheat, mustard, soybean and maize.

Impact of varietal introduction in Mewat

In 11 villages of Mewat, improved varieties of wheat have shown significant increase in yield. All the introduced varieties have out-yielded the conventionally grown varieties and farmers have readily adopted the new varieties, especially the short duration varieties such as WR 544 and HD 2985, which have consistently performed better than the currently grown varieties for four years (Fig 52). Varieties such as HD 2851 and HD 2967 are of long duration and had significantly higher yield in favorable weather conditions as was found during 2011-12 and 2012-13 seasons. These varieties can be highly suitable in seasons where mean seasonal maximum and minimum temperatures do not exceed the threshold values. However, in case of high seasonal temperatures, WR544 is more suitable. This variety, though yielded less than HD 2967, can withstand the variable climate more efficiently. Thus the inter-seasonal differences in yield performance are very minimal.

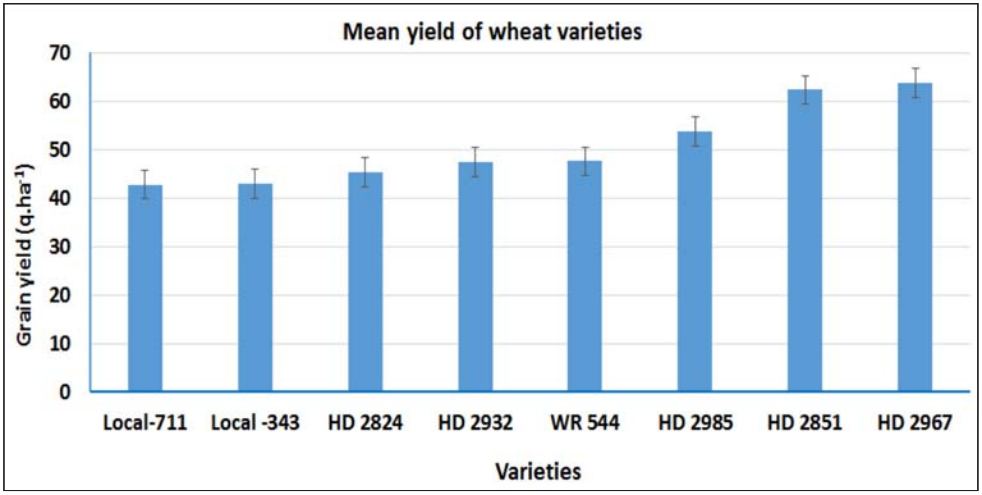


Fig. 52: Yield performance of wheat varieties which have been traditionally grown (WH 711 and PBW 343) and introduced varieties. Each bar is a mean of about 300 farmers. Data from each farm field was collected in $1m^2$ area in 2 to 3 places/field from 11 villages of Mewat.

The impact of adoption of these improved varieties by the farmers was quantified by taking the data on biomass and yield in 1 m^2 area from about 300 farms fields every year. Thus, the data from about 1600 farms were analyzed and summarized. The overall performance of different varieties of wheat in the first year has encouraged farmers to adopt new varieties in entire farm land. This enhanced the overall yield levels in each farm, but at varying magnitude depending on the level of management, as also was indicated by the simulation analysis.

The analysis on change in yield levels due to improved varieties has indicated that the introduction of improved varieties has increased yield levels of farmers under all conditions of management. For instance, with conventional varieties, about 13% of the farmers were getting yield less than 3 Mg/ha; 25% of the farmers were getting yield between 3-4 Mg/ha; while about 60% of the framers could get yield in the range of 4-5 Mg/ha (Fig 53). Only 2% of the farmers used to get 5-6 Mg/ha of wheat yield. However, with the introduction of new varieties, poorly yielding farms have shifted to higher yield levels and hence there was no farmer with low yield of less than 3 Mg/ha. About 21% of the farmers got yield of 3-4 Mg/ha. While about 58% of the farmers got yield in the rage of 4-5 Mg/ha. In addition, about 10% of the farmers achieved wheat yields in the rage of 5-6 Mg/ha. Further, 10% of the farmers could get yields as high as more than 6 Mg/ha. This clearly demonstrated that the farmers could achieve high yields with improved and suitable varieties.

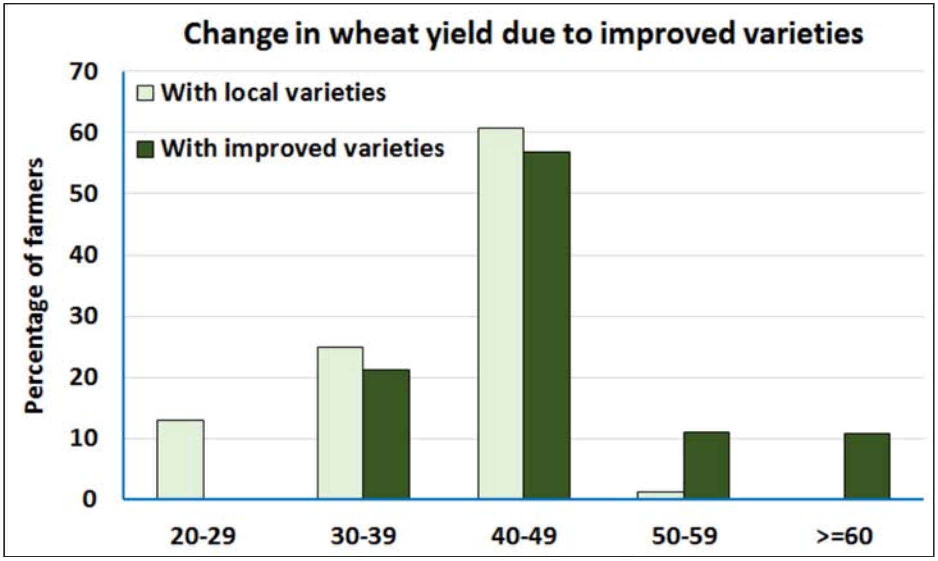


Fig. 53: Shift in farm yield levels due to introduction of improved varieties of wheat. Total number of farmers is about 1600 in 11 villages of Mewat.

Similar analysis on mustard varieties indicated that all the introduced varieties of mustard have significantly out yielded the local variety. In this case also the yield levels of farmers those have adopted improved varieties have gone up (Fig 54). The yield levels with conventional variety could not exceed 2 Mg/ha in most of the cases.

By growing improved varieties such as Pusa Mahak, Pusa Agrani and Pusa Tarak, 50% of the farmers could achieve 2-2.5 Mg/ha of yield. About 5% of the farmers could achieve even higher yields (Fig 55). These results indicate that replacement of old varieties and higher seed replacement rate are required to improve the farm yields in this region.

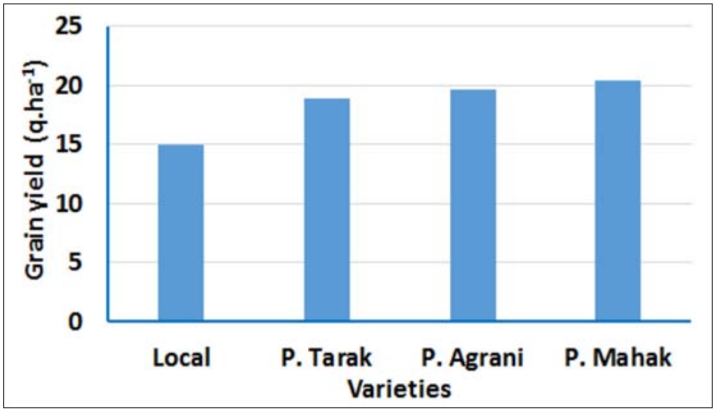


Fig. 54: Yield performance of mustard varieties which are traditionally grown (Local) and introduced varieties. Each bar is a mean of about 350 farmers. Data from each farm field was collected in $1m^2$ area in 2 to 3 places/field from 11 villages of Mewat.

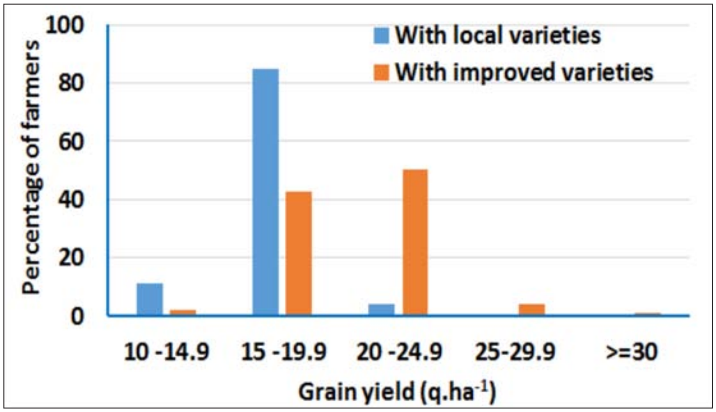


Fig. 55: Shift in yield levels due to introduction of improved varieties of mustard. Total number of farmers is about 1200 from 11 villages of Mewat.

Impact of varietal introduction in Dhar

Similar analysis in Dhar district for about 500 farms in 13 villages indicated that soybean yield improved with change in variety. As in case of Mewat, farmers in Dhar also could produce higher yields with improved varieties thus there has been a shift in the farm yield level from less than 1 Mg/ha to 1.5 Mg/ha in about 20% of the farmers (Fig 56). With the local varieties, soybean yield was about 1 Mg/ha in 30% of the fields and 1.5 Mg/ha in 53% of the fields. A substantial 15% increase in farms with soybean yield of 1.5 to 2 Mg/ha has been noted. Thus in soybean also introduction of new varieties has shifted the low yielding farms to medium yielding forms and medium yielding forms were shifted to high yielding forms as is seen in case of wheat and mustard in Mewat.

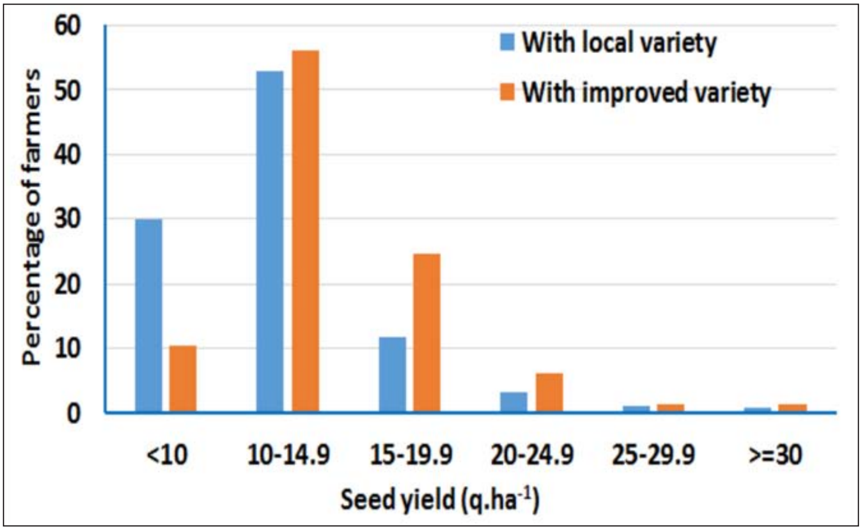


Fig. 56: Shift in farm yield levels due to introduction of improved varieties of soybean. Total number of farmers is about 500 from 13 villages of Dhar.

In case of maize also, introduction of HQPM hybrids has led to increase in yield and shifting about 52% of the lowing yielding farms (less than 1.5 Mg/ha grain yield) to next level of yield of 1.5 to 2.5 Mg/ha; whereas about 3% of farms also yielded 2.5 Mg/ha or more (Fig 57). However, the yield levels are generally low because of low input levels, while the hybrid maize requires more inputs for realizing high yields.

Thus, in 24 villages of two districts, yield could be increased by 8-35% depending on the crop and management (Table 13). Part of the improvement in yield could also be attributed to improved management such as water management, laser leveling as

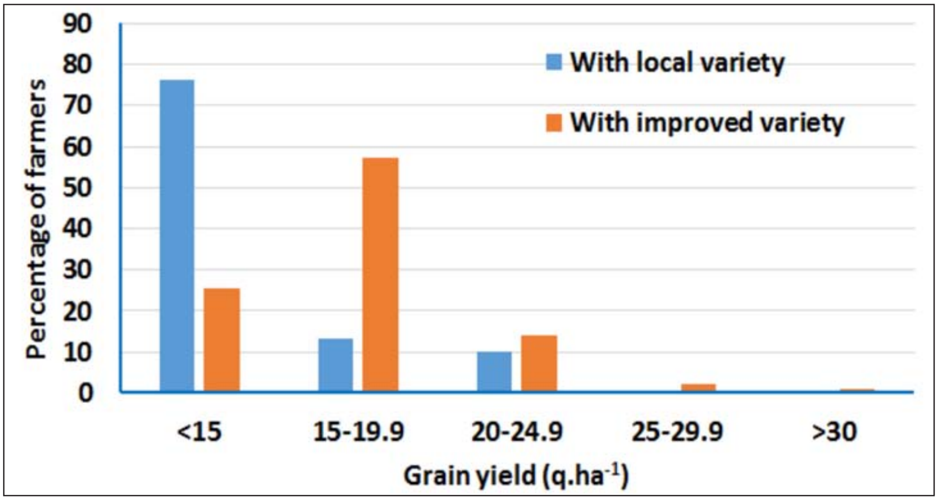


Fig. 57: Shift in farm yield levels due to introduction of hybrid maize (HQPM). Total number of farmers is about 200 from 13 villages of Dhar.

Table 13: Summary of improvement of yield in about 2200 farmers' fields in 24 villages of Mewat and Dhar districts due to introduction of new varieties.

Crop	Improved variety Yield (t/ha)	Farmers' variety yield	% Increase in Yield
Rice	4.63	3.43	28-35%
Wheat	3.71	3.11	20%
Maize	2.52	1.82	28-41%
Mustard	2.16	1.81	8-11%
Chickpea	2.12	1.71	25%
Soybean	1.66	0.92	22-40%

well as adopting better crop protection strategies. Though yield increased in almost all farms, the magnitude varied because of the management level. In spite of this, overall increase in yield is substantial (8-35%) in the region mainly due to the adoption of improved varieties by large number of farmers through 1) direct intervention 2) farmer-farmer interaction and 3) farmers selling of the seed. Overall replacement of old varieties with new ones could be achieved in these regions and the yield has gone up perceptibly. The yield in villages gone up by about 20% in wheat, 8-11% in mustard in Mewat region. Similarly, in Dhar district wheat, chickpea (25%) and soybean yields (22-40%) have improved resulting in significant improvement in the farm income.

Analysis of Adaptation Cost and its Impact on Profitability from Agriculture

Analysis on economics of adaptation impacts was done using intensive data sets collected from 120 farm families. Household (HH) level data included more than 300 parameters for pre-intervention period and post intervention period. Some of the farm families those who were not part of the project in the same village were also sampled to capture the progress despite non-adaptation. Further, some other households from nearby villages were sampled to delineate the spillover effects in the same village. Households were grouped based on the land holding i.e., <2 acre, 2-<4 acre, 4-<6 acre and > 6 acres forming 4 strata. For delineating the profits due to agriculture as well as total household incomes, as well as to delineate the adaptation gains, difference in difference model was used.

Data and methodology

The analysis was focused on two issues from the data collected, i) agricultural profit and ii) the cost of adaptation. Data were collected using the stratified sampling method, a two-step process. Firstly, the three strata viz., Intervention Farmers, Non-Intervention Farmers from Same Village and Non-Intervention Farmers other Village were delineated. In the second step, farmers in each of the three groups were divided on the basis of their land-holding size i.e., <2 Acres, 2-<4 Acres, 4-<6 Acres and >6 Acres. Data were then collected for all 12 groups. Out of 120 households (HH), 81 HHs represented adapted farmers. Another 19 HHs represented non-adapted farmers from same village. Remaining 20 HHs represented non-adapted farmers from other village outside project. An extensive questionnaire was used for capturing the HH information. The total number of variables exceeded 1200 which covered socio-economic details, farm characteristics, farm (crop and livestock) management details, expenditure and income from farm, household secondary income and expenses, assets and liabilities, etc. Out of these, 1030 variables were used to capture the expenses and incomes from important activities (Table 14 and 15). To facilitate comparison, data have been normalized by dividing it with the land-holding size. The focus was on agricultural profit (profit from all crops taken together) and the cost of adaptation which includes expenses on agriculture and the depreciation on agricultural equipment. To facilitate comparison, data were standardized by dividing with the land-holding size. Crop-wise profit values were calculated from respective expenditure and income. The

Table 14: Details of number of variables used for the analysis under each category.

Variable group	Expense variable	Income variable	Profit variable
Before Intervention			
Crops	32	16	16
Other Income	0	104	0
Other Expenses	130	0	0
After Intervention			
Crops	297	99	22
Livestock	10	30	10
Other Income	0	104	0
Other Expenses	130	0	-0
Assets			
Land	12	0	0
Agricultural Equipment	12	0	0
Other implements/ transport vehicles	6	0	0

Table 15: The strata-wise degrees of freedom for modelling the adaptation costs using data from 120 households.

Land holding	Non-Intervention Farmers Same Village and Intervention Farmers	Non-Intervention Farmers Other Village and Intervention Farmers
<2 Acres	18	18
2-<4 Acres	64	66
4-<6 Acres	48	44
>6 Acres	44	52
Total	174	170

opportunity cost of farm family labour based on ongoing wage rate, ongoing rate for self-use of grain or fodder and ongoing rental value of land was also considered wherever applicable. Depreciation on machinery and farm equipment was calculated at 30% on written down value method. This has been used as a measure of cost of adaptation along with the all other agricultural costs. Data for the base period were adjusted with CPI inflation for rural workers (base year 1986-87). This facilitated direct comparison as the difference due to inflation has been eliminated. The data has been adjusted for 2013-14 prices.

Two hypotheses were tested using econometric models

Hypothesis Hypotheses on agricultural profit:

H_0: $Profit_0 = Profit_A$

H_1: $Profit_0 \neq Profit_A$

Where $Profit_0$ is for the initial period (baseline 2009-10) and $Profit_A$ is for post-project period (2013-14).

Hypothesis for cost of adaptation:

H_0: $COA_0 = COA_A$

H_1: $COA_0 \neq COA_A$

Where COA_0 is cost of adaptation for the initial period (baseline 2009-10) and COA_A is cost of adaptation for the final year of the project (2013-14).

Difference in difference (DD) model description

To demonstrate the difference due to the interventions made, the Difference in Difference (DD) model was used. This model is a basic two-way fixed effects model with cross section and time fixed effects. Time series of non-adapted group was used to establish what would have occurred in the absence of the intervention. Two such models were used. The first one compared cost of adaptation and profitability of adapted groups and control (non-adapted groups in the same village) over time for all four strata. The second model compared cost of adaptation and profitability of adapted groups and control (non-adapted groups in other villages) over time for all four strata. The second model has been taken to eliminate spillover effects, if any. Control group identifies the time path of outcomes that would have happened in the absence of the treatment. Here, profit (Y) changes by $Y_{c2} - Y_{c1}$ even without the intervention. So the treatment effect is given by the equation $(Y_{t2}-Y_{t1}) - (Y_{c2}-Y_{c1})$ instead of just $Y_{t2}-Y_{t1}$. This was done after calculating the agricultural profits as well as costs of adaptation for all 3 groups (adapted, non-adapted same village and non-adapted other village) for all 4 strata (<2 acres, 2-<4 acres, 4-<6 acres and >=6 acres). After deriving the cost of adaptation, the household surplus was calculated based on i) agricultural income and ii) after considering all the sources of HH income as well as the expenses. The surplus per capita is expressed based on the agricultural income alone and also based on total HH income.

Agricultural profit and expense per acre from crops

Analysis indicates that the agricultural expense increased over time, more so for the adapted farmers followed by the non-adapted ones from same village (Fig 58). The agricultural expenditure per acre was more in small landholdings of <4 acres. For >=6 acre strata, it is marginally greater for non-adapted ones from other village. Data indicates that adaptation leads to more expenses for small and marginal farmers. Laser levelling of land, use of improved seed, pheromone traps, and laying of new water conveyance systems, sprinklers and rain guns led to higher investment. However, most of these are capital expenses. The agricultural profit rose over time for all types of farmers sampled from the project intervention area. However, the magnitude of profit varied across the three farmer categories (viz., adapted, non-adapted from same village and non-adapted from other village). While the profitability decreased with increase in land holding size in the sample HHs, adaptation to climatic risks led to increase in agricultural profit.

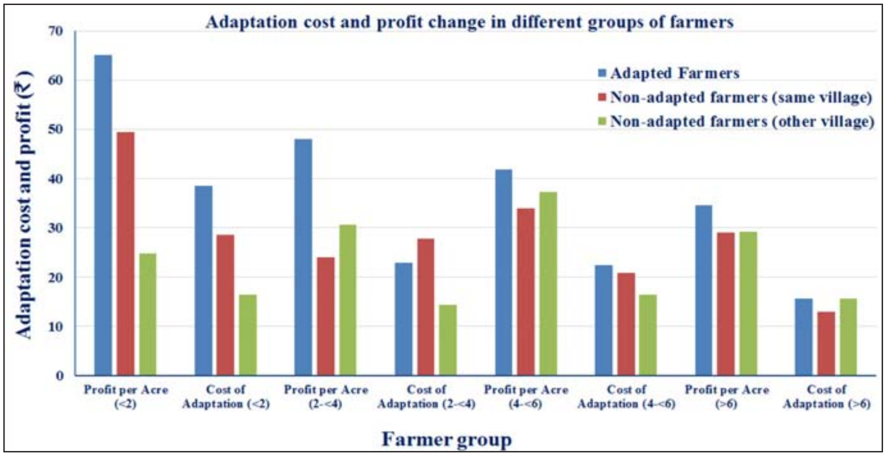
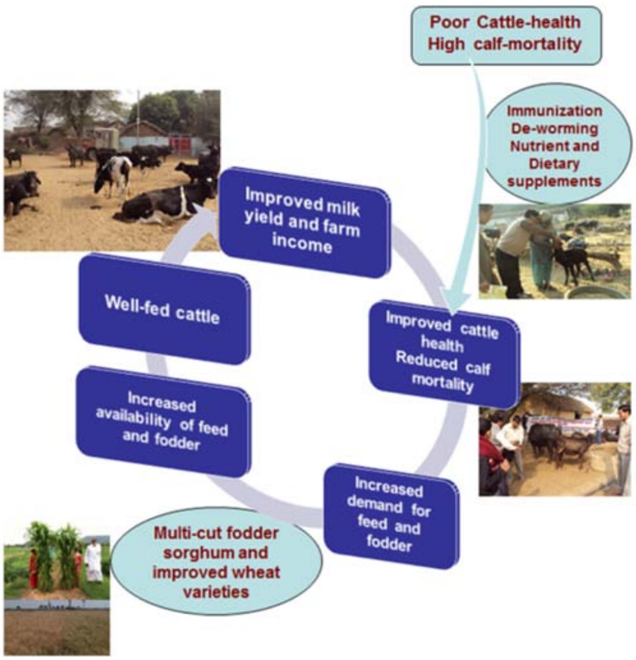


Fig. 58: Landholding based cost of adaptation and change in profit in agriculture in adapted farmers, and non-adapted farmers from same and other (non-project) village.

Agricultural profit from livestock

Poor health condition of livestock led to calf mortality up to 50% in the region. Basic reasons were found to be infections, poor management and non-availability of adequate fodder and feed. Interventions such as immunization, nutrient supplements, deworming, and availability of additional fodder and feed have been very helpful in increasing the profitability in the intervention group of farmers. The milk yield increased at the rate of 1.5 to 2.5 L/animal/day over an average yield of 8L/animal/day.



The annual expenditure on cows varied from ₹ 30,000 to 32,500 while expenditure on buffalo ranged from ₹ 40,000 to 45,000. This included cost of nutrient supplements (@ ₹ 75/kg used for 20 days/animal), deworming and fodder and feed. These costs did not vary across size of land holding. Since milking animals inherently are more profitable than non-milking ones, the average depicted (Fig 59a) might not be a true representation of the livestock productivity. So the profitability of milking-animals is also worked out (Fig 59b), which is more than when all animals are included.

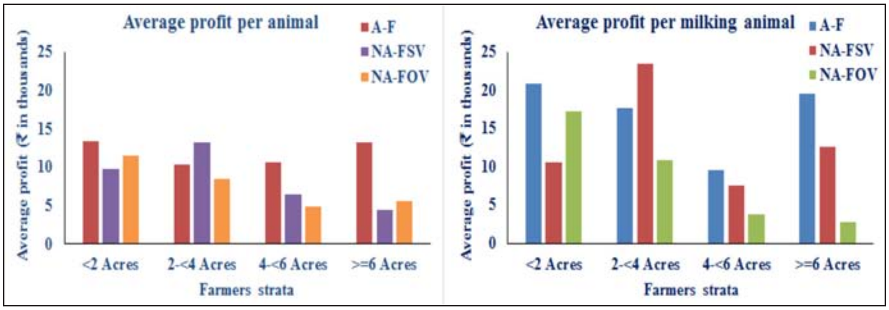


Fig. 59: The profit from (a) livestock and from (b) milking animal to the farmers under different groups. I-intervention farmers; NISV- non-intervention same village farmers; NIOV- non-intervention other village farmers.

Analysis of adaptation cost and its impact on profitability

Difference in difference model was used to analyze the profit and cost of adaptation for all agricultural activities at farm level. These estimates for profit were positive for adapted farmers with respect to the non-adapted farmers of the same (project) village as well as from other (non-project) village. This implies that the per acre profit earned by adapted farmer is more than per acre profit earned by non-adapted farmers, even after factoring for trend and base line profits. The estimate for cost of adaptation implies the difference in the change of per acre expenses and depreciation of farm equipment over time between adapted and non-adapted farmers. It is mostly negative for non-adapted farmers in the same village and mostly positive for non-adapted farmers in other villages. Analysis indicates that the non-adapted farmers in <4 acre groups, particularly those in 2-<4 acre group, have to alter the existing agricultural practices so that their management cost reduces, and the profit due to technological benefit increases. The spillover effect of adaptation strategy seems to be more among farmers with land holding of 4 acres and above in same village as well as in other village. However, farmers with land holding of >=6 acres seem to be spending more for crop management as compared to project intervention farmers of same strata. In <2 acre strata, farmers have to either adjust their crop management without additional cost or incur additional cost for adaptation. By doing so they can achieve significant improvement in profit (Fig 60). In 2-4 acres strata, almost similar trends are found but

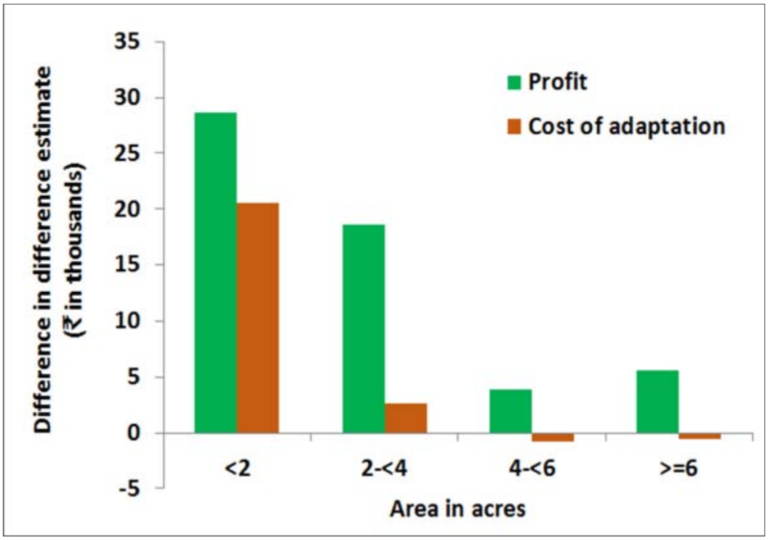
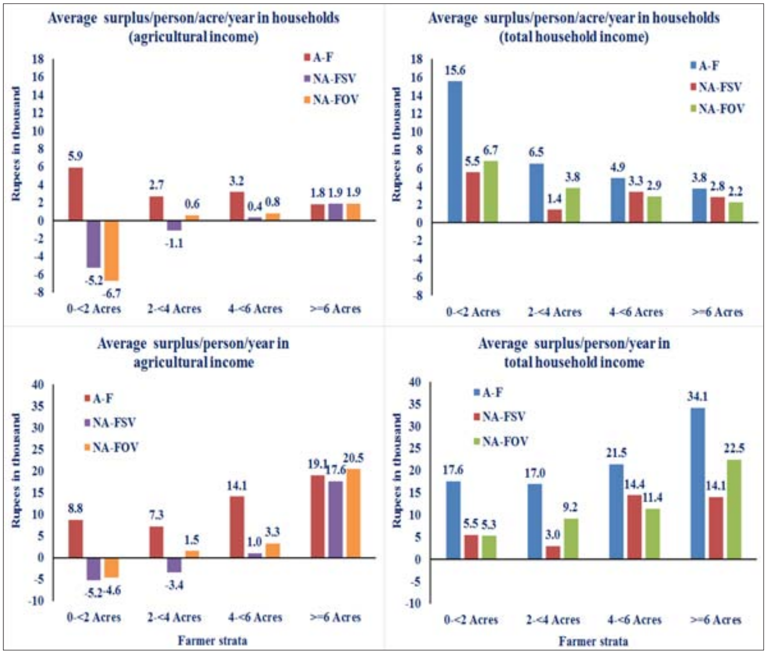


Fig. 60: Difference in difference estimates for profit and adaptation cost for different strata of farmers.

the profit may not increase proportionately. The analysis also indicates that the profit is not directly proportional to the cost of adaptation, if any, among different strata of farmers. Adaptation cost was not same across the strata. In general, small farmers had more adaptation cost than the large farmers. However, the small farmers realized higher profit/unit area. These farmers generally have the cereal-vegetable cropping system. Large holding farmers generally grow cereal based cropping systems thus the profits are less. Large farmers may have to rationalize their management investments for gaining more profits, while small farmers may have to face additional cost for adaptation to climate change.

Analysis on household surplus income

The average surplus income available from total household income (Fig 61a) or agricultural income (Fig 61b) has varied across the strata. Total household income includes the agricultural income as well income from other sources. Average surplus income per person per acre in a year showed a declining trend as the land holding size increased. The adapted farmers of <2 acre land holding could improve income due to the adaptation. The agricultural profit of non-adaptors could not sustain the family expenses, and they had to depend on non-farm income for sustenance. The income contribution from non-agricultural activities seems to be very less in households with



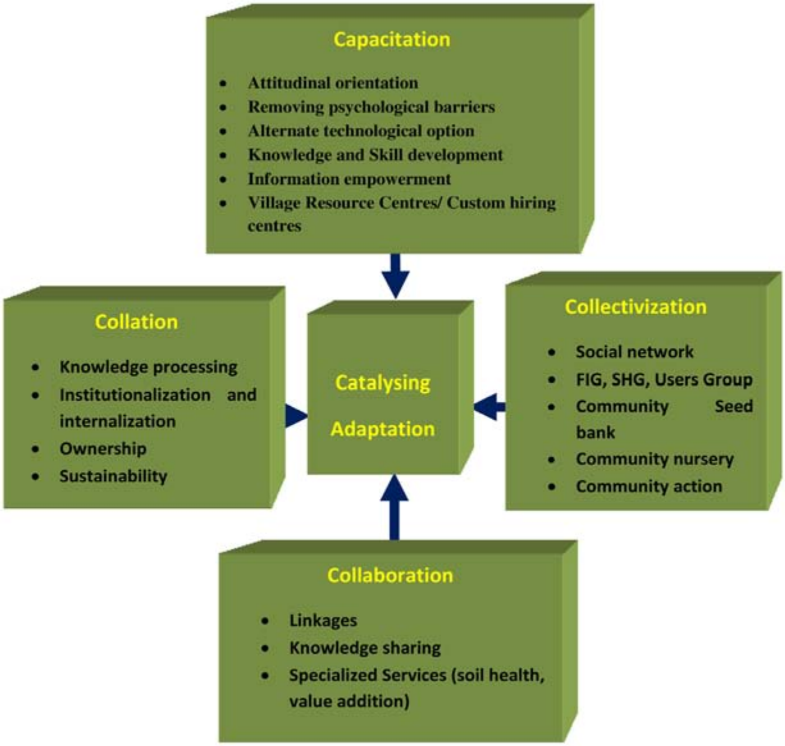
land holding of 4 acre and above. However, these results are specific to the sample HHs. Further, size of the farm families increased as the size of land holding increased. One reason could be joint families living together have bigger farms as compared to nuclear families. In addition they have abundant farm labour at home to manage bigger farms.

When surplus is expressed on landholding basis (Fig 61 c and d), it is clear that farmers with small land holdings can't support themselves with agricultural income alone, without changing their crop management. However, with adaptation, as in case of intervention farmers, a self-sustaining agricultural system could be achieved. The non-intervention farmers in this strata sustained their family through income from other sources than from agriculture alone. Except for the farmers in >= 6 acres strata, adapted farmers exhibit higher surplus in all strata. The per acre surplus increased with the size of land holding.

Crop diversification, improved varieties and growing of horticultural crops are found to be the major reasons for increased profit from agriculture. Findings indicate that growing one grain crop and two vegetable crops during a year can be highly profitable. The farmers growing 3-4 grain crops could increase profits by replacing at least one grain crop with vegetable cultivation.

Extension Strategy for Building Adaptive Capacity of Farmers

Multipronged adaptation options were implemented following the 5-C model where capacitation, catalyzation for adaptation, collaboration, collectivization and collation were followed.



Capacitation

The interventions in action plan majorly focused upon (a) promotion of water harvesting through community based interventions like bund making, small check dam, deepening of bore wells, renovation of water harvesting structures; (b) promotion of efficient utilization of water through use of underground pipeline for water conveyance and irrigation with drip, sprinkler and rain gun systems, (c) introduction of superior crop varieties for high yield and tolerance to stresses. For instance early and terminal heat stress tolerant varieties of wheat, (d) Crop diversification with vegetables for income enhancement and for house hold nutritional security (e) Integration of Resource Conservation Technologies (RCTs), Integrated Pest Management (IPM) and Integrated Nutrient Management (INM) technologies, (f) value addition of the farm produce (g) Promotion of scientific livestock management practices to reduce calf mortality, improve health and nutrition, and enhance milk productivity, (h) use of ICT for information dissemination and (i) capacity building of farming community for not only minimizing the climatic risks but also to improve the overall income from agricultural activities.

The information dissemination was done using mobile based two-way communication system in collaboration with TATA Consultancy Services. The existing one-way communication system (*mKRISHI)* was modified and upgraded to *PUSA-mKRISHI*, a two-way dynamic communication with both push and pull system of information services with integration of information of climate, farm characteristics and technology. Besides pushing the information to users' domain, farmers are capacitated to communicate their field queries through pictures, text SMS and voice mail. Voice mail and graphics could help in better comprehension by farmers with respect to the cause and symptom. This systems works with minimal time lag between

farmers' query and experts' response. An expert console manages the information flow between the users and the subject matter specialists. Such service ensured better preparedness and quality decision making among the farmers. *PUSA-mKRISHI* has been able to connect over 3000 farmers from 62 villages in Dhar and from 17 villages in Mewat.

As a result of these innovations, the farmers could increase the availability and use efficiency of water and other inputs, enhanced crop productivity, higher income and more number of on farm employment days, reduction in migration, and improvement in livelihood and nutritional security. The outcomes amply underlined the appropriateness and applicability of these innovations in rural areas for livelihood security of vulnerable communities.

Collectivization

Social participation and social network have been found as effective indicators for promoting adaptation. It is a fact that effective adaptation would require efficient management of resources like water structures, water, seed, implements, information, etc. Collective action has been found to be pivotal in enabling small scale producers to have adequate access to resources as well as in coping with the stress through exchange and reciprocity of resources with fellow farmers. Therefore, stress was laid upon formation and functioning of farmers' groups such as tomato growers group, brinjal growers group, etc as well women's self-help groups (SHGs). Community seed banks and 'Seed Village'; community nurseries, custom hiring centers, Village Resource Centres (VRCs) for collective use of farm machineries, sharing information and 'Sustainability Fund' were promoted. These VRCs and custom hiring facilities, seed banks enhanced accessibility of farm machineries, processing equipments and seeds among the farmers. These facilitated a large scale adoption of practices like laser leveling, raised bed planting, bund making and improved varieties of crops.

Augmentation of collective actions with formation of village development committees (VDCs), farmers' groups and involvement of Panchayati Raj Institutions for participatory monitoring was emphasized for effective management of community

Mobile seed processing unit in Dhar

Equipment in Village Resource Centre

ponds and water sharing. Social networking was engineered for community sharing of water resources through main pipeline network from the water source along with distribution networks across fields to benefit other farmers whose fields are away from the water source. With water user groups, facilities of irrigation were extended to large areas through underground pipe-lines, rain-guns and sprinklers, and sharing mechanism.

Seed storage bins

Collaboration

With exposure visits and dialogue, linking farmers to local research, development, credit and market institutions was facilitated. Linkage with KVK was instrumental in technological backstopping, services of soil testing and value addition, training on crop and livestock management, enterprise development (mushroom cultivation, vermicomposting, value addition, etc). Linkage with Mother Dairy was useful in awareness about formation of association, quality production, post-harvest handling and transportation of vegetables. The *PUSA mKRISHI* linked the farmers with various departmental services as well as with markets in the locality and nearby town for updates on product rates, etc.

Collation

The farmers' workshops, farmers-scientists interface meet, and stakeholders' workshops were organized for processing the experiences of leanings from successful adaptation. Sharing of experiences facilitated social ratification and internalization of the adaptation.

Summary of Adaptation Interventions and their Impacts

These adaptation strategies are expected to be up-scaled and out-scaled with suitable modifications to meet the local needs and with adequate support of the governments and institutions at various levels. Mainstreaming the climate change adaptation strategies into agricultural developmental projects and initiatives is the need of the hour to make the Indian farmer resilient to climatic risks and secure the sustainable livelihoods. Significant outputs and outcome are summarized below:

Significant outputs and outcome

S&T Innovations	Intervention	Impact	Income enhancement
Improved, heat and drought tolerant crop varieties	Varietal demonstrations of wheat, mustard, soybean, gram, maize, multi-cut fodder sorghum, green gram	52 to 64% increase in Seed replacement rate Average 15-25% yield enhancement	Average 35-65% additional income
Improved crop management	Recommended seed rate, sowing method, dose and scheduling fertilizer and irrigation	Yield increase by 12-15%; coupled with 25% & 30% reduction in CO_2 emission / ha & water saving respectively	₹ ~10000/ha
Improved crop management and nursery of horticultural crops	Shade net house (56 nos.) of 9X6 m size, pheromone traps (1500 nos.), raised bed sowing of vegetable crop Papaya orchard (100 nos.)	Improved seed of vegetables and horticulture plants etc. Household availability of fruits for nutritional supplement	Net profit ₹ ~ 30,000/ha /season
Water Saving Technologies	Laser levelling (3 ha), Underground pipeline (3 km), sprinkler/ rain gun (10 units), drip (22 units) Open-well deepening (>100 open wells), de-silting and renovation of community ponds (6 nos.)	~ 40% water saving, ~25% irrigation-time saving and ~25% reduction in CO_2 gas emission. 10 ha area increased under irrigation Water Users Groups	Through increased yields and area under irrigation; reduced cost of irrigation

Livestock/ animal husbandry interventions	De-worming, vaccination, medicine, green fodder, nutrient Supplement, mange feed and water	12-15% increase in milk yield & 20-25% reduction in calf mortality	₹ ~ 8000/ lactation period/ house hold
Value addition of farm produce	Dhalia making- Machine (14 nos.); chilli powder machine- (3 nos.); dhaal making machines (5 nos.)	Benefit for groups in income enhancement, self-employment for women (chilli powder making with own brand)	₹ 3000 – 4000/ quintal
Secondary skill development for income enhancement	Tailoring training and machines (24 nos.)	Women economic empowerment	₹ ~ 3000/month/ Household
Seed village	Mobile seed processing units (one) Seed village (11 nos.) Community seed banks (22 bins)	Increased income to seed –selling farmers	₹ 70,00-80,000/ ha.
Village resource centres	Information sharing, dissemination and custom hiring machinery per centre Power spray (5 nos.), seed-cum- fertilizer drill (4 nos.), Rotavator (1) Zero-till seed drill (4) Audio system (1)	Availability and application of agricultural machinery, improved cultivation, drudgery reduction; dissemination of information	Confounded in the enhanced income of all other activities
Knowledge and weather-based farm advisory	*mKRISHI* - two- way mobile communication services over 36000 voice alerts, 46000 weather forecasts mKRISHI regular and IVR services (>2000 nos.)	Informed decision making, Early Warning System	Crop and resource savings confounded in all activities

Socio-economic relevance

The farmers of these four districts shared about various climatic risks, which affected agriculture as well as their livelihoods. They reported drought as the major thriving risk in the area. Decreasing amount of rainfall marked with irregular distribution and un-timeliness as well as early withdrawal was observed by the farmers. Cold winter, fog, heat-stress and dust storms were the other climatic risks in the area.

Excessive evaporation affected the crop growth and yield as irrigation is a serious limitation. Early heat stress affected crop stand while terminal heat stress affected the grain filling and ultimately the yield of wheat crop.

In the cluster areas of Dhar district in Madhya Pradesh, soybean and wheat are the principal crops of kharif and rabi seasons, respectively. Various combinations of cropping (soybean / maize / cotton / ground nut / urd / vegetables – wheat / chickpea) are predominantly followed for risk adjustment in the event of climatic vagaries. The cropping intensity was observed to be about 127 per cent. The average yield of major crops in cluster villages was less than the district and state average. However, yield gaps existed in comparison to potential yields. There is a very high technological gap in areas of resource conservation especially water resources, farming practices, integrated pest management, and soil fertility management. Gap is also high in area of seed replacement and crop production management.

Financial constraints, poor irrigation facilities, lack of animal health care facilities, lack of human health care facilities, low market return of agricultural produce, high cost of inputs, poor supply of electricity, incidence of insect pests and diseases in crops, lack of technological know-how, unavailability of quality seeds and planting materials, lack of collective action, lack of marketing facilities, lack of credit facilities, tenancy constraints, undulation of land and problem soil and water quality (salinity) were the major non-climatic risks which affect the livelihoods of the people. Scarcity of rainfall and constraints in irrigation have made farmers realize about water conservation.

Specific Recommendations

- The comprehensive approach followed in this project viz., i) identification of current and future climatic risks, ii) risks to livelihoods due to climatic variability, iii) develop scientifically derived and community based sustainable rural livelihood strategies and their implementation to minimize adverse climatic impact on climatically vulnerable districts and iv) convergence and capacity building of the stakeholders on strategies for resilient farm income and livelihood may be followed as a model for adaptation to climate change and up-scaled with appropriation to suit specific needs.
- Higher productivity through high temperature /heat and drought resilient varieties and improved adaptation technologies of selected crops (wheat, mustard, chickpea, maize, pearl millet, soybean in drought prone districts) under adaptation to climate change initiatives, rendered higher income, enhanced safeguard against income fluctuations due to climatic risks.
- Mixed cropping is a promising adaptation strategy for small-scale tribal farmers to reduce risk of complete crop failure. Some farmers have started growing maize together with cowpea/vegetables, which mitigates the risk from reduced vegetable yields. Both crops are well adapted to water scarce conditions prevailing in Dhar and grow well even on relatively poor soils. Mixed cropping of different vegetables like eggplant, tomatoes and ladyfingers together with maize is working well too. Despite mixed fields are more labour intensive for farmers, they do have several other advantages. They are less prone to pest attacks, allow for a diversified diet, spread the risk of having no yields at all from failure of one crop and thus generate additional income in the long run.
- The most limiting factor in the drought prone study area is water availability. Thus, the key to build up climate resilience in Madhya Pradesh lies in the water sector. Improving rainwater-harvesting capacities to take advantage of existing harvesting structures by either renovatesing, extending and building new nullah-bunds on drainage channels, community tanks and ponds in order to enlarge storage capacity of water for benefitting the community.
- In tribal dominated Dhar district, water resource sharing proved to be a viable adaptation strategy. Forming small water user group (3-7 household), sharing common under-ground pipeline for carrying water from source to closer to their

field clusters, sharing sprinkler /rain gun sets help in reducing water consumption and guaranteeing equal distribution of scarce resources; thus guaranteeing stable production of crops. Successful example of a functioned self-regulated sustainable rainwater harvesting and groundwater management based on social regulation schemes is found in Badnawar cluster (Villages) in Dhar district.

- Investment in sprinklers, rain gun and / or drip irrigation is a good way to enhance water use efficiency and also to reduce water consumption in agriculture sector. However, most of the time farmers are not capable of making investments of that scale. In most cases farmers were not aware of all government schemes that had provisions of subsidies for such irrigation facilities in those areas.
- People's participation in water resources development and management-experience of working with the community in Dhar, Madhya Pradesh showed that some technical/specialist supports needed for design and development of local/village/cluster level water harvesting plan as well as it's efficient implementation could have a huge impact on water availability. People's participation can be ensured through local 'active NGOs' in those areas.
- Sustainable water management practices were vital to adaptation in water scarce and drought prone areas of Dhar district. Deepening of existing wells and digging of new wells may bring some relief in the short run but it not a sustainable practice if the root of the problem is not addressed. However, new recharge sites (renovated WHS, community ponds/Percolation tanks at upper reaches of watershed, etc.) may strengthen the scarce resource sustainablity and encourage judicious use and discourage misuse/overuse.
- Strengthening village development committee (VDC) including a member from local Panchayat was the guiding force for collective decision making and monitoring and sustainability of the management bodies. Build-up capacity of the VDC for

financial management of contributory 'sustainablity or village fund', which takes care of management task as well as maintenance of the existing infrastructure also assured sustainability of interventions.

- Capacity building in the area of integrated water saving technologies and locally suitable agricultural techniques, agriculture and livelihood diversification, conservation agriculture, organic farming practices, etc. is needed.
- The other most important thing in local level of adaptation was to preserve the seeds of farmers' varieties that have high temperature and drought tolerance.
- Increase seed-cum-grain storage capacity at community level for ensuring food security during crisis period. Besides production, emphases needs to be laid upon seed as well as grain storage facilities. The farmers should be encouraged to stock seeds of temperature and drought tolerant varieties.
- In climate change adaptation programme, assured access to weather forecast is of paramount importance. Majority of farmers in the project areas (especially, Mewat, Dhar etc.) reported to have no access to such information or were simply not aware of these services. However, mKRISHI service platform under this project assured adequate distribution of wether forecast information to remote villages through two-way communication mobile technology. This technology may be upscaled.

Lessons learnt

- Adaptation to climate change is location specific and is a social learning process.
- Community based adaptation forms bottom-up livelihood perspectives while and government programmes from top-down approaches.
- As climate change further declines the adaptive capacity of farmers, there is a need to launch adaptation measures now and plan for upscaling.
- Adaptation to climate change and development go together at the local level but need more convergence of programme and sharing of information at cluster/block level.
- Strengthening research-development linkages to address the future risks.
- Monitoring on-going adaptation practices, alert on risks of mal-adaptation, and establishing links with policy making.
- Strengthening institutions with clearly firm responsibilities at community level (encourage local leadership), and linkage with panchayat/block/district programmes.

Terminology

Adaptation

The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Adaptation assessment

The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

Adaptive capacity

The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities.

Adaptation costs

Costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition cost.

Baseline/reference

The baseline (or reference) is the state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.

Climate

In a narrow sense climate is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period of time is 30 years, as defined by the World Meteorological Organisation (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind.

Climate change (a per IPCC)

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate change (UNFCC)

A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Climate extreme (extreme weather or climate event)

The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'

Climate model

A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved.

Climate projection

A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/ concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate

Crop simulation model

Model is a simple representation of a complex phenomenon. Crop simulation model is a computer software to mimic the behaviour of crop growth. A model becomes dynamic if it has the time step. Dynamic simulation models generally have one day as the dynamic time step.

Early warning system

The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities, and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

Flood

The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

Forecast/Prediction

When a projection is branded "most likely" it becomes a forecast or prediction. A forecast is often obtained using deterministic models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections.

Impacts

Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Potential impacts

All impacts that may occur given a projected change in climate, without considering adaptation.

Residual impacts

The impacts of climate change that would occur after adaptation. See also aggregate impacts, market impacts, and non-market impacts

Mitigation (of climate change)

A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Projection

A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty.

Regional Climate Model

A regional climate model (RCM) is a high resolution climate model that covers a limited area of the globe, typically 5,000 km x 5,000 km, with a typical horizontal resolution of 50 km. RCMs are based on physical laws represented by mathematical equations that are solved using a three-dimensional grid. Hence RCMs are comprehensive physical models, usually including theatmosphere and land surface components of the climate system, and containing representations of the important processes within the climate system (e.g., cloud, radiation, rainfall, soil hydrology).

RCM- PRECIS

PRECIS is a Regional Climate Model. The PRECIS climate model is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described. Boundary conditions are required at the limits of the model's domain to provide the meteorological forcing for the RCM.

Scenario

A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline. See also Climate scenario and Emissions scenario.

Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Weather

Atmospheric condition at any given time or place. Weather is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season.

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Acknowledgements

Sincere thanks to the grants support by the World Bank –Global Environment Facility programme and NAIP-Indian Council of Agricultural Research. Thanks are also due to Dr. H.S. Gupta, Consortium Leader and Director, Indian Agricultural Research Institute, New Delhi, and Joint Directors of Indian Agricultural Research Institute for constant support and encouragement. Sincere thanks to the farmers of four districts for carrying out adaptation intervention and especially to the 120 households of Mewat for sparing their time for providing information during the survey. Thanks are also due to all those who were involved directly or indirectly with the project activities.

Notes

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