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Impacts of Climate Change on Growth and Yield of Rice and Wheat in the Upper Ganga Basin

Glossary

DSSAT	Decision Support System for Agrotechnology Transfer
WTGROWS	Wheat growth model
ORYZA	Crop - weather model for prediction of rice
PRECIS	Providing Regional Climates for Impacts Studies
IITM	Indian Institute of Tropical Meteorology
RUE	Radiation Use Efficiency
LAI	Leaf Area Index

Impacts of Climate Change on Growth and Yield of Rice and Wheat in the Upper Ganga Basin

Impacts of climate change on growth and yield of rice and wheat in the Upper Ganga Basin

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Editorial inputs: Divya Mohan and Shirish Sinha, WWF-India

WWF-India commissioned this study to the Indian Agricultural Research Institute (IARI) to assess the impacts of climate change on the rice and wheat production system in the Upper Ganga Basin. This report presents the results based on climate change scenarios and identifies potential adaptation strategies. The study is part of the 'Climate Change Impacts on Freshwater Ecosystems in the Himalayas' (CCIFEH) project. The CCIFEH project is a joint initiative of WWF-India and WWF-Nepal, supported by WWF-Netherlands and aims to study and understand climate change impacts on freshwater ecosystems, livelihoods and the economy.

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EXECUTIVE SUMMARY

Change in climate conditions and the frequency of natural disasters in recent times has made it imperative to find lasting adaptation solutions for the agriculture sector. Given that almost 60 % of the country's population relies on this sector for its livelihood and that it contributes approximately 15.7% of India's GDP, an analysis of changes which could impact crop yields and subsequently lead to an instable food security scenario is necessary. Taking this into account, the present study by IARI, commissioned by WWF-India focuses on the impacts of climate change on crops like wheat and rice in the Upper Ganga Basin.

Owing to the substantial dependence on the south-west monsoon, agriculture in India is considered to be quite sensitive to the ongoing and projected changes in climate parameters. Given the rise of global average surface temperatures by 0.74°C in the last 100 years, efficient management of the agricultural sector using appropriate adaptation strategies has become a necessity.

ALMOST 60% OF THE COUNTRY'S POPULATION RELIES ON AGRICULTURE FOR ITS LIVELIHOOD

This report presents the findings of a study carried out to understand and analyse the future impacts of climate change on the growth and yield of rice and wheat in the Upper Ganga Basin.

The study also identifies potential adaptation strategies for the agriculture sector to cope with the projected impacts in this region. This research carried by IARI uses the InfoCrop model to make projections of yield and growth change of these two crops based on climate projections in 2070-2100.

The results indicate that climate change is projected to increase the temperature more in the A2 scenario than in the B2 scenario and the projected increase is relatively higher during the *Rabi* rather than in the *Kharif* season.

Adaptation options such as growing improved varieties, efficient irrigation, fertiliser management and application of additional nitrogen can reduce the impacts of climate change on rice and wheat crops in the region. Improved crop management, as well as, better risk management through an early warning system and crop insurance policies can also be beneficial measures to reduce the vulnerability of the farmers.

1.0 INTRODUCTION

Indian agriculture scenario

In the backdrop of a burgeoning population where food and nutritional security is a constant challenge, agriculture has emerged as a key component for the growth of the Indian economy. With a contribution of approximately 15.7 % to India's GDP and 10.23 % (provisional) to the total exports in 2008 -09 as suggested by the latest reports[1] and the fact that it provides employment to 58.2% of the population, a consistent growth of this sector is vital to meet other challenges as well.

In India, agriculture is substantially dependent on the south-west monsoon. This is evident from the fact that the net irrigated area of the country is 60.9 million hectares from a total net sown area of 140.3 million hectares. Thus, a large part of the net sown area is rain-fed, thereby making the agriculture sector in India very sensitive to any changes in the pattern of rainfall. For instance, the impact of overall deficit of 23% in rainfall during the south-west monsoon in 2009-10, which adversely affected *Kharif* production, is reflected in the agriculture GDP growth rate which shows a decline of 0.2 per cent as against the previous year's growth rate of 1.6 per cent.

General trend of climate change

The changes in climate parameters are being felt globally in the form of changes in temperature and rainfall pattern. The global atmospheric concentration of carbon dioxide, a greenhouse gas (GHG) largely responsible for global warming, has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Similarly, the global atmospheric concentration of methane and nitrous oxides, other important GHGs, has also increased considerably resulting in the warming of the climate system by 0.74°C between 1906 and 2005 (*IPCC, 2007 b*). Of the last 12 years (1995–2006), 11 years have been recorded as the warmest in the instrumental record of global surface temperature (since 1850). The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. This rate was faster over 1993 to 2003, about 3.1 mm per year (*IPCC, 2007 a*).

There is also a global trend of an increased frequency of droughts as well as heavy precipitation events over many regions. Cold days, cold nights and frost events have become less frequent, while hot days, hot nights and heat waves have become more frequent. It is also likely that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. The IPCC (2007) projected that temperature increase by the end of this century is expected to be in the range 1.8 to 4.0°C. For the Indian region (South Asia), the IPCC projected 0.5 to 1.2°C rise in temperature by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future development scenario (*IPCC 2007 b*).

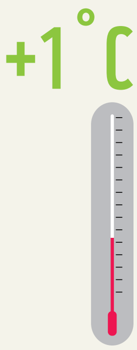
Overall, the temperature rise is likely to be much higher during the winter (*Rabi*) rather than in the rainy season (*Kharif*). It is projected that by the end of the 21st century, rainfall over India will increase by 10-12% and the mean annual temperature by 3-5°C. The warming is more pronounced over land areas with a maximum increase over northern India.

These environmental changes are likely to increase the pressure on Indian agriculture, in addition to the on-going stresses of yield stagnation, land-use, competition for land, water and other resources and globalisation. It is estimated that by 2020, food grain requirement would be almost 30-50% more than the current demand (*Paroda and Kumar, 2000*). This will have to be produced from the same or even the shrinking land resource due to increasing competition for land and other resources by the non-agricultural sector.

[1]*Annual Report 2009 -2010, Department of Agriculture & Co – operation, Ministry of Agriculture, Government of India*

Observed impacts of climate change on Indian agriculture

Increasing temperatures and changes in rainfall pattern are also impacting the agricultural sector. Although there are ongoing studies to understand the impacts, some studies have shown certain trends. Researchers use several methods to assess the impact of climatic variability ranging from the traditional approach of historical data analyses by various statistical tools to controlled environment studies and Crop Growth Simulation models in order to understand the impact of temperature, rainfall and CO_2 on crop growth and yield (*Aggarwal, 2008*).



A 1°C RISE IN TEMPERATURE CAN POSSIBLY RESULT IN 4-5 MILLION TONNES OF LOSS IN WHEAT PRODUCTION

An increase in ambient CO_2 is usually considered beneficial as it results in increased photosynthesis in several crops, especially those with C3 mechanism of photosynthesis. However, despite these beneficial effects, the combined increase in temperature and variability of rainfall would considerably affect food production. Some studies indicate a probability of 10-40 % loss in crop production in India with increase in temperature by 2080–2100 (*As cited in Aggarwal, 2008*). These assumptions are based in a business as usual scenario, with no new technology development and with either no or limited adaptation by all stakeholders.

Some studies by the Indian Agricultural Research Institute (IARI) indicate the possibility of loss of 4-5 million tonnes in wheat production with every rise of 1° C temperature throughout the growing period even after considering carbon fertilisation but no other adaptation benefits. The modelling based estimates are in line with the field observations. For example, in March 2004, temperatures were higher in the Indo–Gangetic plains by 3-6°C, which is equivalent to almost 1°C/ day over the whole crop season. As a result, wheat crop matured earlier by 10-20 days and wheat production dropped by more than 4 million tonnes in the country. Other crops such as mustard, tomato, onion, garlic and other vegetable and fruit crops also suffered losses (*Aggarwal, 2008*).

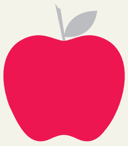
An analysis of the historical trends in yields of rice (*Oryza sativa L.*) and wheat (*Triticum aestivum L.* emend Fiori & Paol.) crops in the Indo–Gangetic plains using regional statistics, long term fertility experiments, other conventional field experiments and the crop simulation models has shown that rice yields during the last three decades are showing a declining trend and this may be partly related to the gradual change in weather conditions in the last two decades (*As cited in Aggarwal, 2008*).

Few studies were conducted using calibrated and validated InfoCrop- MAIZE and SORGHUM models for analysing the impacts of increase in temperature, CO_2 and change in rainfall on maize and sorghum crops apart from HadCM3 A2a scenario for 2020, 2050 and 2080 in major maize and sorghum producing regions of India (*Byjesh et al., 2010, Srivastava et al., 2010*). It was revealed that climate change may reduce the productivity of maize in some regions of India during both monsoon and winter seasons. With a rise in temperature, the reduction in yields is projected to be larger in warmer locations than the other locations. However, in areas with low temperature during winter, the crop is projected to benefit. Some changes in the phenology like reduction in flowering days of the crop were also observed. Also, in the event of reduction in rainfall by 30% to 40%, the water stress predominates in crop failure than the rise in temperature. In the case of Sorghum, climate change impacts are projected to reduce the grain yield of sorghum more during winter than in monsoon in many sorghum producing regions. The yield loss may be huge for locations where current temperatures are already high.

An increase in the temperature can also affect yield of temperate crops, such as apple. This is illustrated by a significant decrease observed in average productivity of apples in Kullu and Shimla (Himachal Pradesh) in the last few years. A key reason for this could be a trend of inadequate chilling in recent decades, crucial for good apple yields. This seems to have resulted in a shift of the apple belt to higher elevations. The new areas of apple cultivation have appeared in Lahaul and Spiti and upper reaches of Kinnaur district of Himachal Pradesh (*Bhagat et al., 2009*).

A rise in the temperature may also have a significant effect on the quality of cotton (*Gossypium sp.*), fruits, vegetables, tea (*Camelia sinensis* (L.), coffee, aromatic and medicinal plants. The nutritional quality of cereals and pulses may also be moderately affected which subsequently will have consequences for nutritional security of several developing countries where cereals are the primary diet (*Aggarwal., 2008*).

This report presents a study which evaluates the impact of climate change on the growth and yield of rice and wheat crops in relation to future climate change scenarios in the Upper Ganga Basin. It also identifies the potential adaptation strategies for sustaining the yield of these crops.



INCREASE IN TEMPERATURE HAS RESULTED IN A SHIFT OF THE APPLE BELT TO HIGHER ELEVATIONS

2.0 STUDY AREA

The study area consisted of 11 districts i.e, Haridwar, Dehradun, Bijnor, Muzaffarnagar, Meerut, Jyotiba Phule Nagar, Ghaziabad, Bulandshahr, Badaun, Aligarh and Etah in Uttarakhand and Uttar Pradesh, in the Upper Ganga Basin (Fig. 1). This region is predominantly irrigated and is dependent on the river Ganga. Wheat is the major *Rabi* crop and rice is the major *Kharif* crop in this region. The soils are alluvial with pH 5.1 to 6.2, bulk density 1.41 and water holding capacity 33-36% (Table 1).

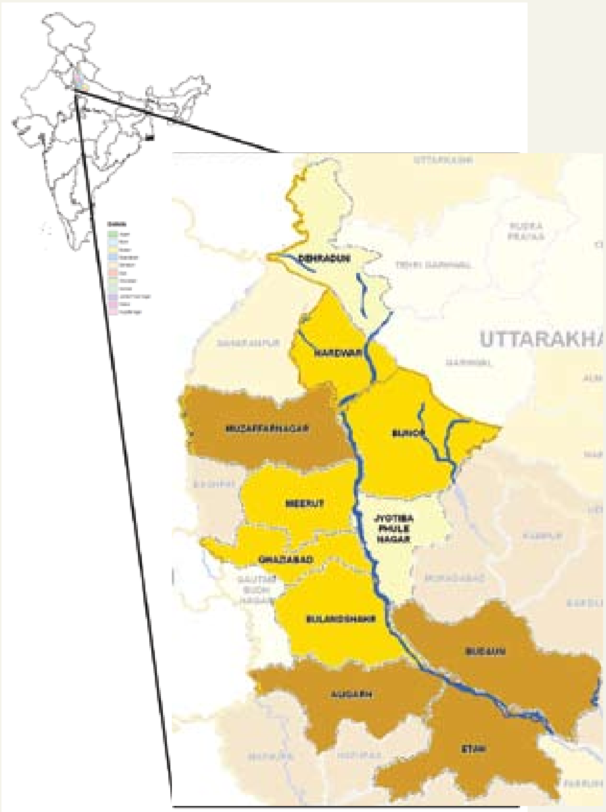


Figure 1
Study area comprising 11 districts in north-west Uttar Pradesh and South-west Uttarakhand

Climate in the study area

The daily gridded ($1^o \times 1^o$) weather data for the region, obtained from the India Meteorological Department (IMD), Pune was used for this analysis. During 1969-1990, the mean maximum temperature of the region during *Kharif* season (June to September) ranged from 25 to 31^{o}C and the mean minimum temperature ranged from 17.4 to 23^{o}C. The south-west part of the region was warmer compared to the northern regions. The monsoon rainfall varied significantly ranging from 570 mm to 1100 mm during June to September. The northern districts received more rainfall compared to the west and south-west districts. The Himalayan foothills were wetter and cooler than the west and south-west plains.

The temperature during the *Rabi* season (November to March) was comparatively lower with the mean maximum temperature ranging from 19.8 to 27^{o}C and the minimum temperature ranging from 6.9 to 11^{o}C. The region also received a small amount of rainfall (35 mm to 250 mm) during this season.

Table 1
Soil characteristics in the study region.

Soil characteristics	Value
Sand (%)	42-47
Clay (%)	21
Bulk density (Mg m^{-3})	1.41
pH	5.1-6.2
Electric conductivity (dS m^{-1})	~0.1
Water content at field capacity (%)	33-36
Water content at wilting point (%)	16-18

Source: ISRIC, World Soil Information, The Netherlands

Characterisation of agriculture in the study area

Wheat, which is grown in the *Rabi* season, is the major crop in this area. Rice is grown during the *Kharif* season. The area under rice varied from 24 to 56 thousand hectares in different districts and the area under wheat varied from 110 to 287 thousand hectares (Table 2). The productivity of rice is higher in Bijnor followed by Muzaffarnagar and Bulandshahr districts. For wheat, Meerut and Bulandshahr districts had higher productivity compared to the other districts.

In this region, rice and wheat crops are cultivated with assured irrigation. Almost the entire area under wheat and rice is irrigated. Rice is unirrigated only in two districts viz. Etah and Badaun and it is approximately 12-18% of the area (Table 2). Considering the predominance of irrigated agriculture, a simulation analysis was done for the irrigated situations to match the baseline situation.

Table 2
Area, production and productivity of rice and wheat in the study districts

District	Rice				Wheat			
	Area under irrigation ('000 ha)	% area under irrigation	Production ('000 t)	Productivity (kg.ha^{-1})	Area ('000 ha)	% area under irrigation	Production ('000 t)	Productivity (kg.ha^{-1})
Muzaffarnagar	24.47	99.7	63.54	2597	131	99.9	431.78	3296
Meerut	37.7	100.0	94.14	2497	263.19	100.0	909.16	3454
Bulandshahr	51.63	99.9	126.52	2451	220.97	100.0	756.16	3422
Aligarh	41.12	93.4	92.46	2249	287.56	98.8	845.03	2939
Etah	36.43	81.7	73.33	2013	202.35	99.7	510.31	2522
Badaun	56.76	88.0	87.87	1548	270.58	99.0	676.46	2500
Bijnor	44.72	96.0	127.73	2856	110.42	95.2	293.83	2661
Jyotibha Phule Nagar	162.54	99.0	383.72	2361	288.99	99.9	733.94	2540
Ghaziabad	NA	100.0	NA	NA	NA	99.9	NA	NA
Haridwar	62.7	NA	172.2	2747	19.7	NA	45.03	2287
Dehradun	13.62	NA	24.19	1776	28.32	NA	49.46	1746

Source: Department of Agricultural Statistics and Cooperation, Ministry of Agriculture, GOI (2004), Agricultural census (Agricultural Census Division, Ministry of Agriculture, GOI) 2005-06

In this region, a small area is under maize, pearl millet and sorghum among cereals; chick pea and pigeon pea among pulses; mustard, ground nut, sesamum and sunflower among oilseed. In addition to these crops, sugarcane, cotton, potato and vegetables are also grown in these districts.

3.0 STUDY METHODOLOGY

In the present scenario, crop growth simulation models are considered a good means of studying interaction effects of CO_2, rainfall and temperature. These models simulate the effect of daily changes on weather (including those caused by climate change) for any location on growth and yield of a crop. The DSSAT series, InfoCrop, ORYZA and WTGROWS are some examples of such crop models which have been used in many studies. InfoCrop, an indigenous decision support system based on crop models is now increasingly being used to assess the vulnerability of agriculture to climate change and for optimising crop management in temporal regions.

Methodology for simulating impacts of climate change and adaptation strategies
Simulation analysis was carried out on the impact of climate change on wheat and rice crops in 11 districts of the study region. The simulation using the InfoCrop models (*Aggarwal et al., 2006a, 2006b*) for wheat and rice were carried out with inputs of the gridded weather data from the India Meteorological Department (IMD), soil data from the National Bureau of Soil Survey and Land Use Planning (NBSSLUP) and World Soil Information (ISRIC, The Netherlands), climate change scenarios data for 2080 Scenarios of A2 and B2 (PRECIS, IITM) and finally crop management and genetic coefficients for respective crop varieties.

InfoCrop model

THE INFOCROP MODEL IS A GENERIC CROP GROWTH MODEL WHICH CAN SIMULATE THE EFFECTS OF FLUCTUATING TEMPERATURE AND RAINFALL, AS WELL AS, CO_2 LEVELS ON THE GROWTH AND YIELD OF A CROP FOR ANY LOCATION

Model description
The InfoCrop is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements (including planting, nitrogen, residue and irrigation) and major pests on crop growth and yield (*Aggarwal et al., 2006a*). The model considers different crop development and growth processes influencing the yield. Total crop growth period in the model is divided into three phases viz. sowing to seedling emergence, seedling emergence to anthesis and the storage organ filling phases. The model requires genetic coefficients like thermal time for phenological stages, potential grain weight, specific leaf area, maximum relative growth rate and maximum RUE of the crop varieties. The model also requires crop management inputs such as the time of planting, application time, the amount of fertiliser and irrigation and soil data (pH, texture, thickness, bulk density, saturated hydraulic conductivity, organic carbon, water holding capacity and permanent wilting point). Location specific daily weather data (solar radiation, maximum and minimum temperatures, rainfall, wind speed and vapour pressure) are also required to simulate crop performance. The outputs are based on the source-sink balance of the crop in relation to its environment.

In the InfoCrop, change in temperature, CO_2, and rainfall are simulated in the following ways:

1. The total development of a crop is calculated by integrating the temperature-driven development rates of the phases from sowing to seedling emergence, seedling emergence to anthesis and storage organ filling phases. The rate of development is linearly related to the daily mean temperature above base temperature up to the optimum temperature. Above this, the rate decreases. Therefore, depending upon the threshold temperature of a region, an increase in temperature generally accelerates phenology and hence the crop duration is reduced.

2. Dry matter production is a function of RUE, photosynthetically active radiation, total LAI, and a crop/cultivar specific light interception coefficient. The RUE is further governed by a crop-specific response of photosynthesis to temperature, water, nitrogen availability and other biotic factors.

3. The net dry matter available each day for crop growth is partitioned as a crop-specific function of the development stage.

4. In the initial stages of crop growth, leaf area formation is controlled by temperature. The senescence of leaves is also dependent on temperature.

5. Temperature influences potential evapo-transpiration. The water stress is determined as the ratio of actual water uptake and potential transpiration. It accelerates phenological development, decreases gross photosynthesis, alters the allocation pattern of assimilates to different organs and accelerates the rate of senescence.

6. Adverse temperature during meiosis stage can significantly increase sterility. In InfoCrop, a part of the storage organ becomes sterile if either maximum or minimum temperatures of the day deviate from their respective threshold values during a short period between anthesis and a few days afterwards. This reduces the number of storage organs available subsequently for accumulating weight. The storage organ starts filling up shortly after anthesis with a rate depending upon temperature, potential filling rate and the level of dry matter available for their growth.

7. The influence of rainfall is operated in the model through soil water balance.

Model calibration and validation
The model is well calibrated for several annual crops such as wheat, rice, maize, sorghum, potato, soybean, chick pea, mustard, ground nut, cotton and coconut, and also a perennial plantation. The calibrated and validated models of rice and wheat were used for simulating the yields during the baseline period (1969-1990).

Simulation analysis

Processing of input data
Weather: The IMD daily gridded data 1º x 1º on rainfall, minimum and maximum temperatures were processed using the MS-Excel macro and was arranged grid-wise. These data were converted to InfoCrop weather file format using a custom-made software. Thus annual files for 22 years (1969-1990) each for all corresponding grids were made. In simulations, solar radiation was calculated by the model based on Hagreaves method, suitable for Indian conditions (Bandyopadhyay et al., 2008). Since the weather data was lacking on wind velocity, the evapo-transpiration was estimated in the model using the Priestly-Taylor method.

Soil data: The data on soil parameters such as texture, water holding characteristics, bulk density, soil pH, depth of soil layers 1, 2 and 3, etc. were obtained from NBSSLUP, Nagpur. Apart from this, the data on soil series from ISRIC, World Soil Information, The Netherlands was also used. The data was input grid-wise into the model.

Varietal coefficients: The simulations were done on the assumption that the farmers have successfully optimised their resources in terms of variety and sowing time. For this purpose, short, medium and long duration varieties were grown in three periods. The first batch was sown at the right time, the second was late while the third was sown very late in all possible combinations. From these simulations, the optimised sowing time and variety were identified and the grain yield was obtained.

Management: In order to mimic the field conditions, the crop was provided with fertilisers and irrigation as practiced by the farmers. Both wheat and rice are predominantly grown as the irrigated crops in the study region.

Scenarios: The monthly data on climate change scenarios for A2-2080[2] and B2-2080[3], derived from PRECIS (provided by IITM), were processed to obtain the change fields for input into the model for coupling with the baseline weather.

Simulation of baseline yields
The simulations were carried out for optimised sowing time and variety under the management of farmers practices for 22 years (1969-1990). The mean yield of 22 years thus derived was taken as the baseline yield. Further, these yields were calibrated to get the current yields.

LOW COST OPTIONS, HAVE BEEN TESTED AS ADAPTATION STRATEGIES TO ASSESS THE ADAPTIVE CAPACITY OF CROPS TO CLIMATE CHANGE

Impact Assessment
The impact of climate change on grain yield of crops was studied using A2-2080 and B2-2080 scenarios derived from the PRECIS RCM. The PRECIS is a Regional Climate Model with HadCM3 as its GCM. The PRECIS model's climate change outputs on temperature (minimum and maximum) and rainfall for A2-2080 and B2-2080 scenarios were processed to couple the baseline weather data. The projected CO_2 levels as per Bern climate change model for respective scenarios were also included in the model for simulations. All other simulation conditions were maintained as explained earlier. After calibrating the simulated baseline yields (1969-1990) to current yields, net change in grain yield in future climate scenarios was expressed as the percentage change from current mean yields.

Adaptation and vulnerability analysis

Low cost options, independently and in combination were tested as adaptation strategies to assess the adaptive capacity of crops to climate change. These are:
a) The usage of short, medium and long duration variety
b) A change in sowing time which includes early, as well as, late sowing relative to current sowing time
c) A change in the seed rate as a surrogate for seed replacement by the farmers
d) A change in the irrigation and fertilisers as a surrogate for increased use efficiency of irrigation and fertilisers
e) Application of additional fertiliser

A combination of these was put in the model and it was run for climate change scenarios to identify the most suitable adaptation combination. The combinations, which gave the highest yield in each scenario, were taken as the best suitable adaptation option. Overall, more than 10 million simulations were carried out for this entire analysis. The net yield gain is expressed as the relative change from the mean current yield. The net vulnerability in respective scenario was obtained from the following formula:

> *Vulnerability* (yield loss, even after adaptation, from current) = *Impact* (yield loss due to climate change) - *Adaptation gain*

In instances where impacts are positive, simulations were run for similar adaptation strategies for quantifying the additional benefits and thus net vulnerability values in these situations represent net positive impacts maximized with additional adaptation measures.

[2]*The A2 scenario describes a very heterogeneous world with a focus on self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.*

[3]*The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.*

4.0 ANALYSIS & RESULTS

Characterisation of climate change scenarios in the study area

In a scenario of changing climate and evolving technologies, it is necessary to introduce crops which can withstand fluctuating temperature and other natural factors. This is illustrated in the two scenarios reflected in this report. The PRECIS (RCM based on HadCM3) outputs for the A2-2080 scenarios indicate that the mean maximum temperature is to increase by 3.37-4.75°C during *Kharif* season and 5.14-6.25°C during the *Rabi* season (Fig. 2 and 5). Similarly, mean minimum temperature is projected to increase by 5.08-5.75°C during *Rabi* as compared to 3.76 to 4°C during *Kharif* season (Fig. 3 and 6). The temperature is projected to increase more in the areas which are warmer at present. An increase in the temperature is relatively less in the hilly areas of Dehradun, Haridwar and Bijnor. Rainfall during *Kharif* is projected to increase significantly in the north and north-east parts of the study region, while no perceptible change is projected for the western and southern parts comprising Etah, Aligarh, Bulandshahr and Ghaziabad (Fig. 4). On the other hand, *Rabi* rainfall is projected to increase marginally in the southern and eastern parts of the study area comprising Etah, Bulandshahar, Aligarh, Badaun and JP Nagar (Fig. 6). Currently, these regions receive very less rainfall during the *Rabi* season as compared to the northern districts.

As far as the B2-2080 scenario is concerned, the mean maximum temperature during *Kharif* is projected to rise in the range of 2.54-3.75°C while the mean minimum temperature is projected to rise by 2.34 to 3.25°C. The increase is projected to be higher in western and southern parts of the region. Changes in the *Kharif* rainfall are almost similar to that of the A2 scenario but with lower magnitude and lower variations in spatial pattern. During the *Rabi* season, an increase in mean maximum temperature is projected to be in the range of 2.75 to 3.5°C while an increase in the mean minimum temperature is projected to be in the range of 3.29-3.6°C. A change in the minimum temperature is almost uniform in the entire region, except for western parts of Etah, Ghaziabad and Aligarh. The rainfall changes were almost similar to that of the A2-2080 projections.

Among the scenarios, temperatures are projected to be higher in the A2-2080 scenario than in the B2-2080 scenario. *Kharif* rainfall is projected to increase more in the A2 than in the B2 scenario. On the other hand, rainfall during the *Rabi* season is projected to decrease in the A2 while it is projected to increase in the B2 scenario.

Figure 2

Mean maximum temperatures during *Kharif* season for the baseline period (1969-1990) and projected increase in temperature (°C) from baseline in PRECIS A2-2080 and B2-2080 scenarios in the study region

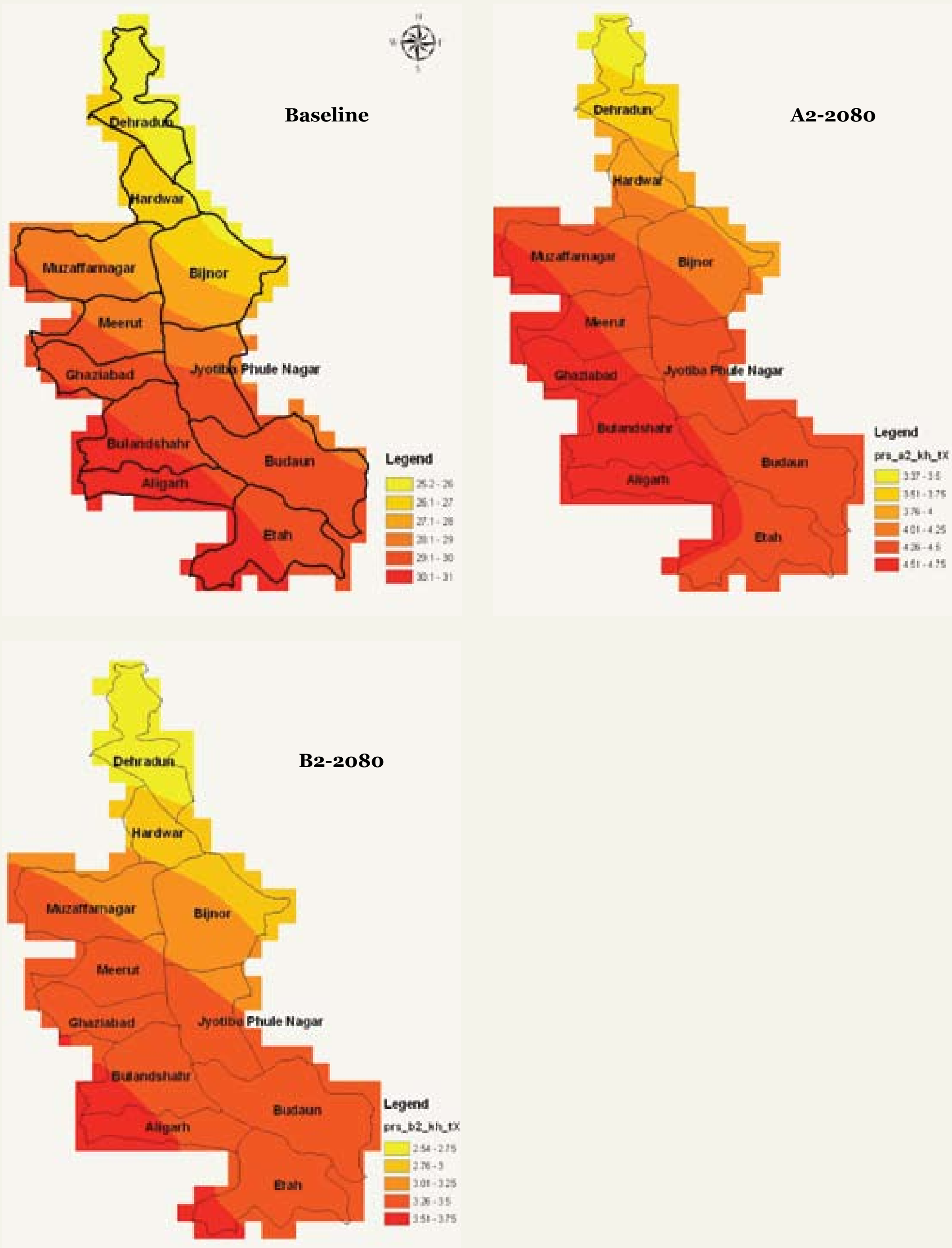


Figure 3

Mean minimum temperatures during *Kharif* season for the baseline period (1969-1990) and projected increase in temperature (°C) from baseline in PRECIS A2-2080 and B2-2080 scenarios in the study region

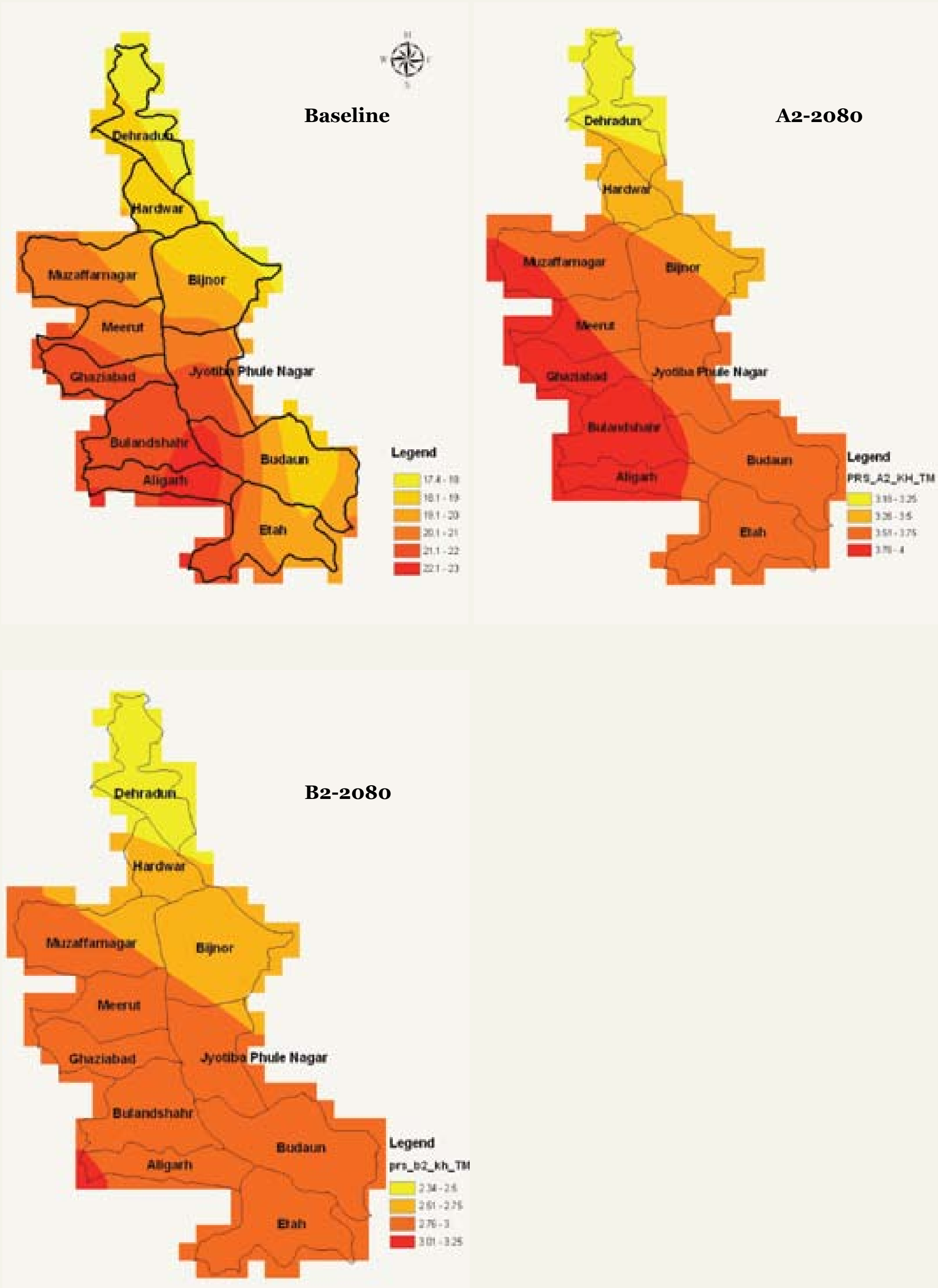
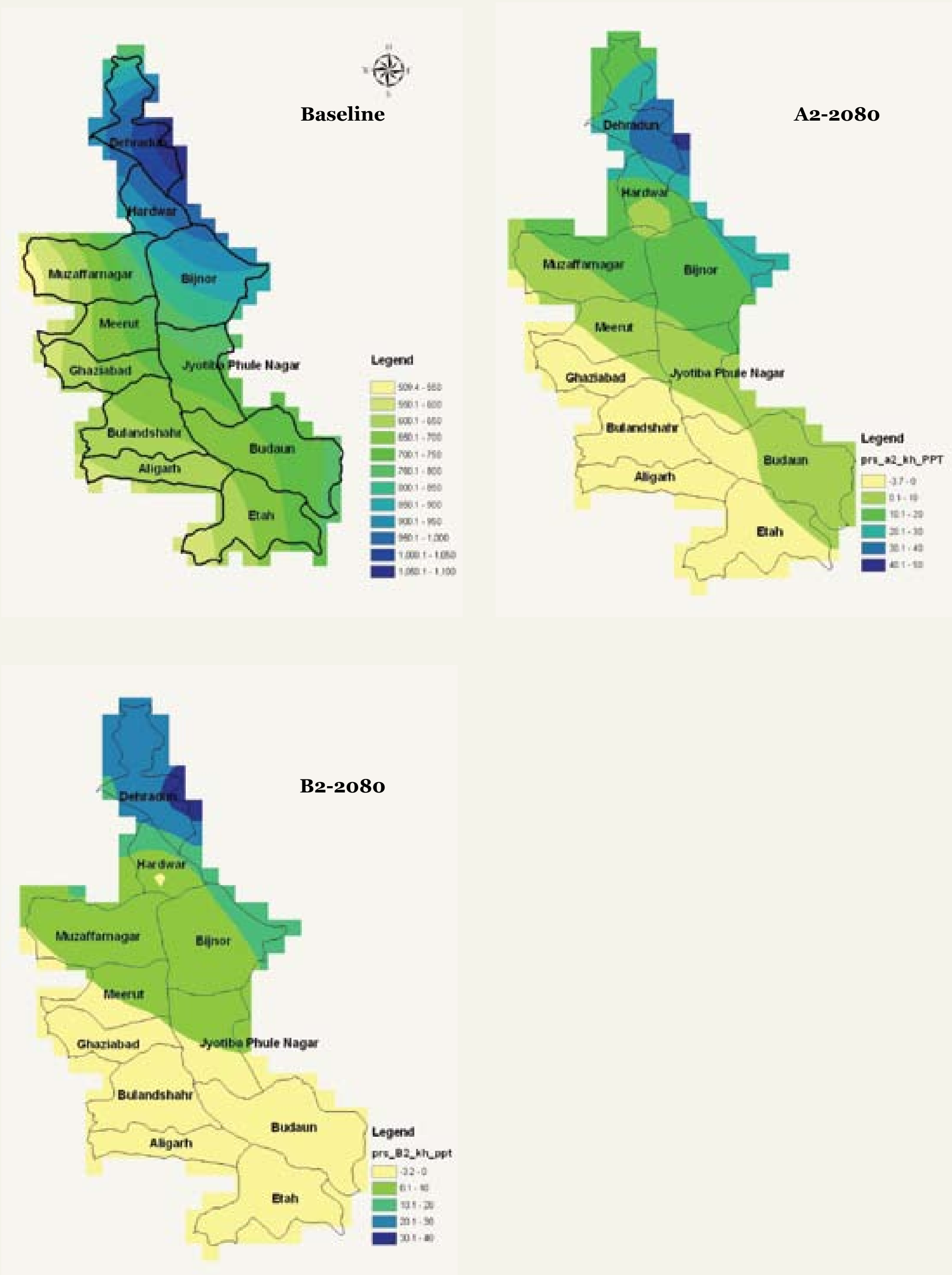


Figure 4

Mean rainfall (mm) during *Kharif* season for the baseline period (1969-1990), and projected change (% from baseline) in rainfall in PRECIS A2 2080 and B2-2080 scenarios in the study region



Mean maximum temperatures during *Rabi* season for the baseline period (1969-1990), and projected increase in temperature (°C) from baseline in PRECIS A2-2080 and B2-2080 scenarios in the study region

Figure 5

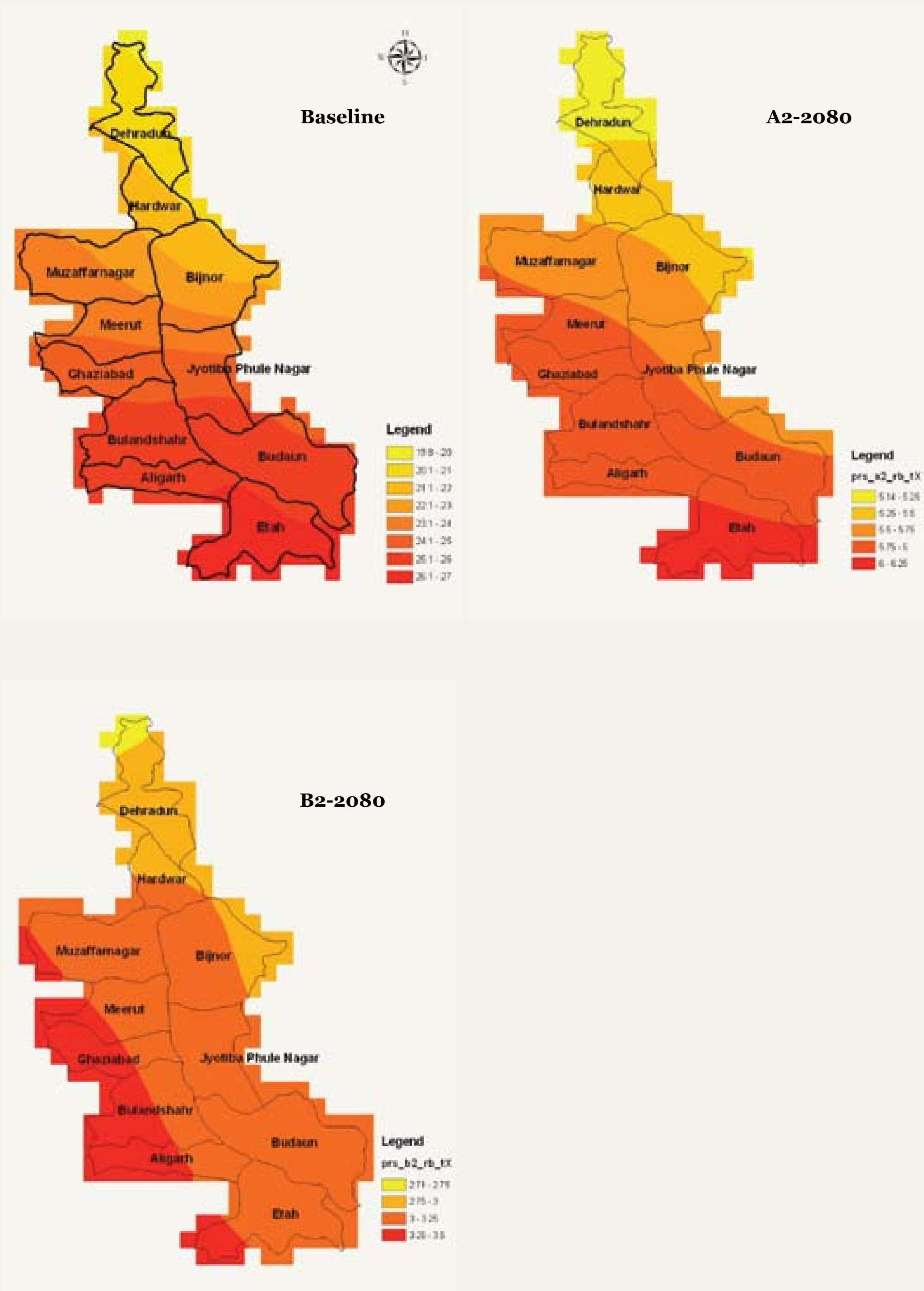
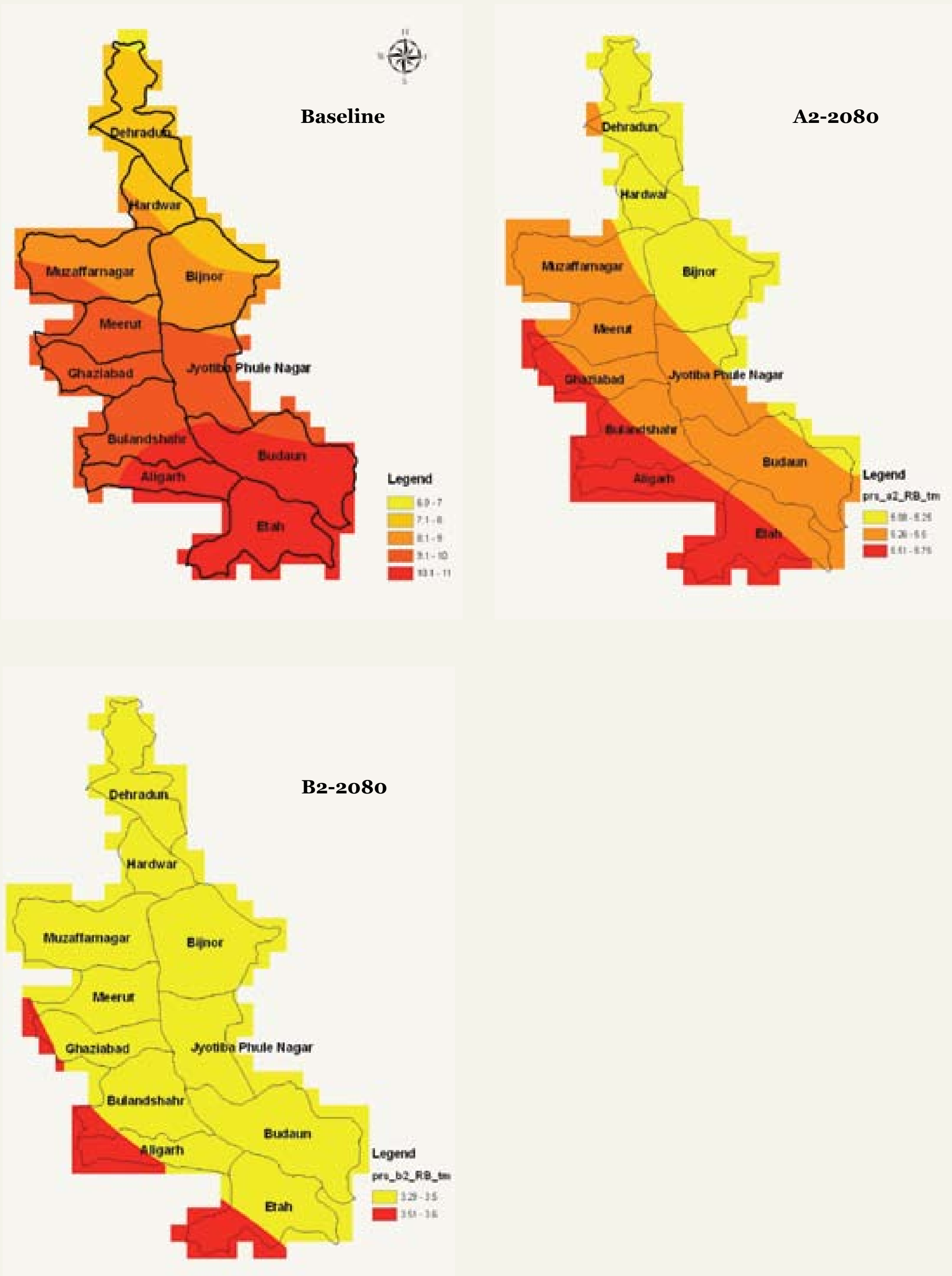


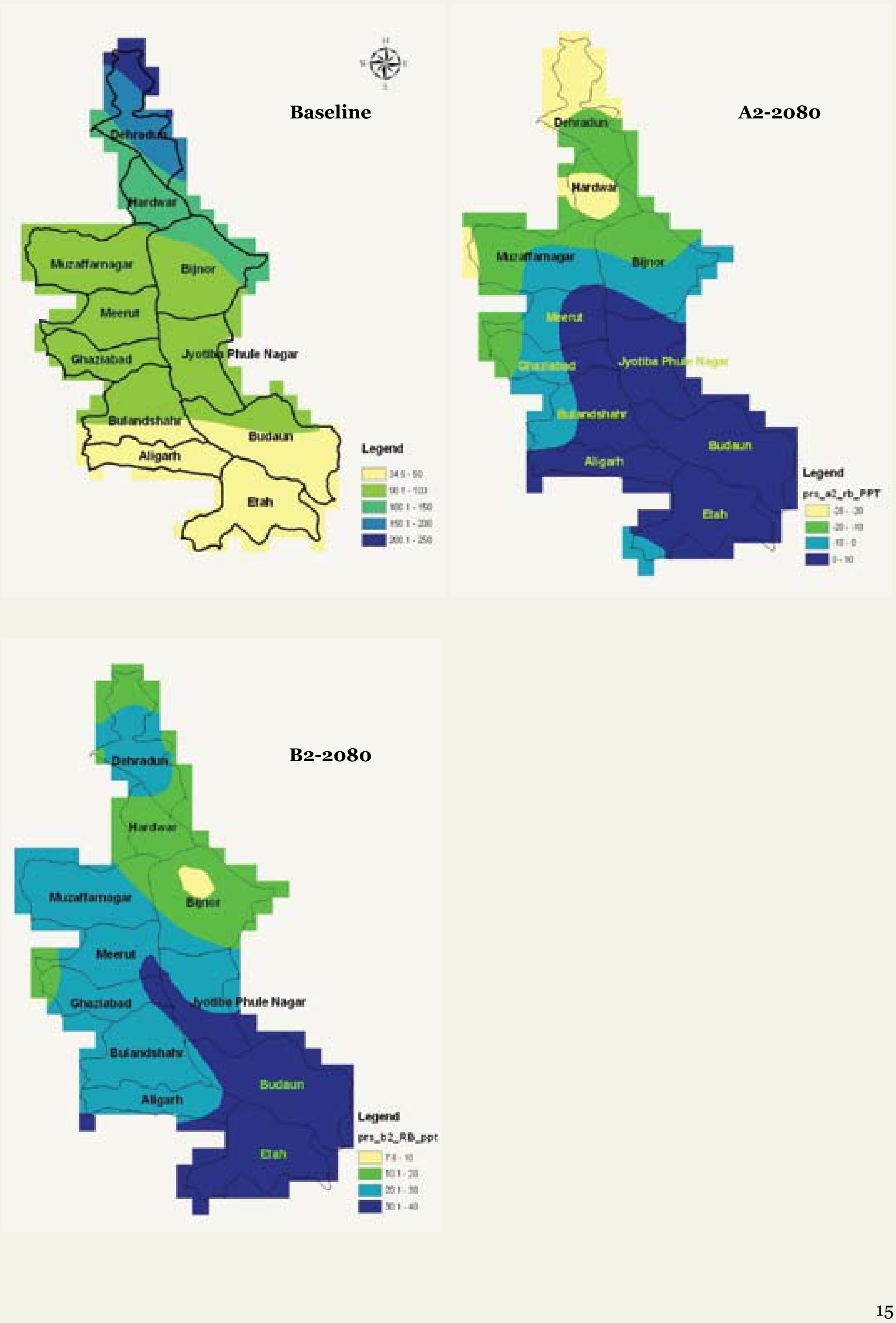
Figure 6

Mean minimum temperatures during *Rabi* season for the baseline period (1969-1990) and projected increase in temperature (°C) from baseline in PRECIS A2-2080 and B2-2080 scenarios in the study region



Mean rainfall (mm) during *Rabi* season for the baseline period (1969-1990), and projected change (% from baseline) in rainfall in PRECIS A2-2080 and B2-2080 scenarios in the study region

Figure 7



Quantification of the impact of climate change on rice

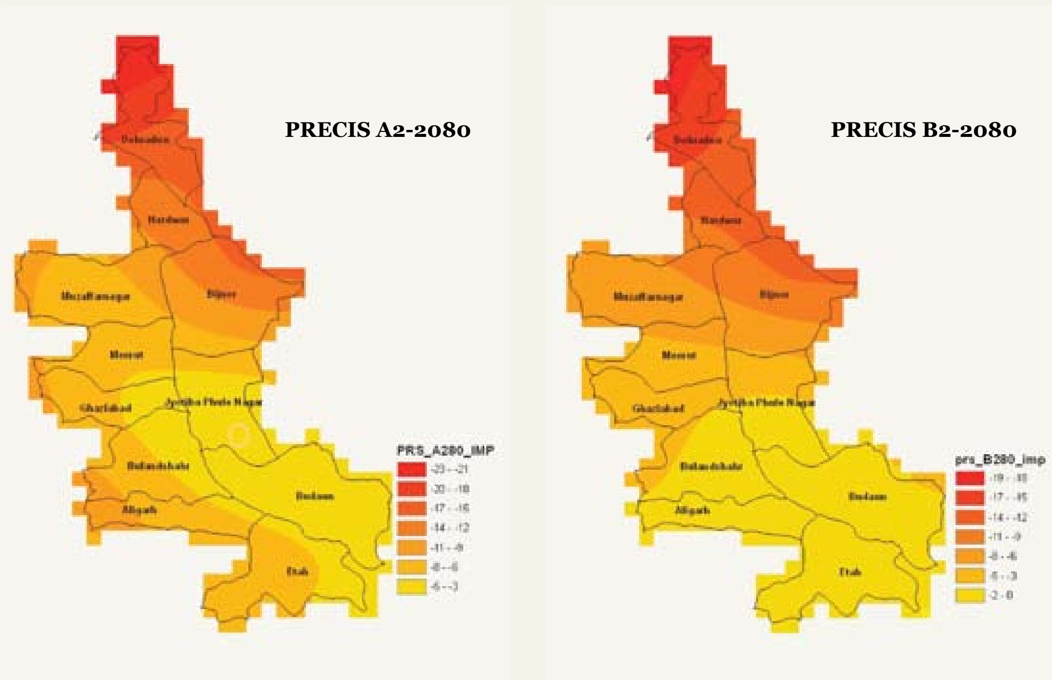
The simulation analysis indicated that irrigated rice is likely to lose the yields up to 23% in many parts of the study region. The parts which are likely to face more yield loss as per A2-2080 scenario are in Dehradun, Haridwar, Bijnor, JP Nagar, Etah and Badaun districts (Fig. 8). On the other hand in B2-2080 scenario, the yield loss is projected to be more in Dehradun, Haridwar and Bijnor districts. The yield loss is projected to be more in high rainfall zones, where rainfall is projected to increase further. This may lead to more cloudy days and thus can cause reduction in the yield.

The high rainfall related soil erosion, loss of crop due to extreme events of rainfall are some of the likely reasons for such trend. The losses are likely to increase if irrigation sources dwindle or sink to lower levels than the current level.

Further analysis indicated that chances of having years with improved yields in these areas is more in B2 than in A2 scenario (Figure 8). On the other hand, years experiencing loss in rice yield is likely to be more in A2 scenario than in B2 scenario. Based on the entire region, three probabilities can be drawn according to the model outputs. First, one out of every three years could have improved yields than the current. Second, in one out of three years the crop loss is likely to be about 10 percent. And third, one out of every three years, crop loss is likely to be more than 10% even extending up to 30%. On the other hand, in A2-2080 scenario, the yield may be higher than current only one in every 10 years period, while six out of every 10 years may lose yield up to 10% and three out of every 10 years may lose yields even up to 30%.

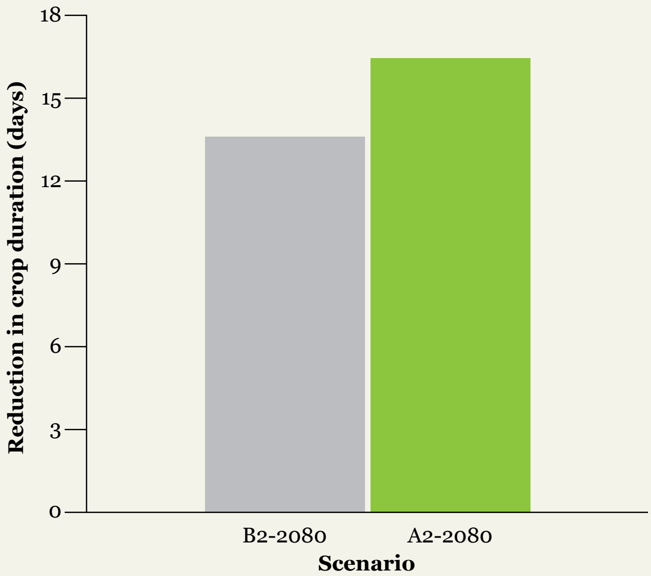
Figure 8

Projected yield loss of irrigated paddy due to climate change in 11 districts of study area under PRECIS A2-2080 and B2-2080 scenarios. Relative yield change (% deviation) is from the current yields



The results indicated that rice in northern region of the study area is projected to be more affected by climate change compared to the southern region. The analysis indicated that the crop duration in future climate scenarios is likely to reduce (Fig. 9) because of the increase in temperature as high temperatures are reported to hasten the crop phenology. The reduction in crop duration is projected to be about 13 days in B2 and about 17 days in A2 scenarios. This reduction in crop duration is projected to cause overall yield loss in the region, which is likely to be around 5% in B2-2080 and -9% in A2-2080 scenarios (Fig. 9). An analysis indicated that projected increase in CO_2 in A2 and B2-2080 scenarios is not enough to compensate for the impact of high temperature.

Figure 9 Projected probability of reduction in crop duration in the study area under PRECIS A2-2080 and B2-2080 scenarios. The changes are relative to those of the baseline period of 1969-1990



Strategies for adapting rice to climate change

Since climate change is projected to reduce the rice yields in most parts of the study region, it is imperative that the adaptation strategies are derived to minimise the adverse impacts. To facilitate this, a simulation analysis was done with low-cost adaptation strategies which included improved crop variety, change in variety and improved crop management, change in sowing time, efficient utilisation of irrigation and fertiliser, increased seed replacement by the farmers and increased fertiliser application. A combination of these was placed in the model and it was run for climate change scenarios to identify alternate suitable adaptation combinations.

The results indicated that just by changing the variety which has a duration similar to that of current variety, the farmers can minimise the impacts of climate change in A2-2080 scenario. Gains though this adaptation strategy are likely to be up to 12%. However, in most parts of the study region, projected gains are only up to 3%. A change in the variety can substantially benefit Dehradun, Haridwar, Bijnor, Aligarh and Bulandsahahr districts. Even then, the net vulnerability of the region is projected to be up to 15% (Fig. 10).

Figure 10

Adaptation gains due to change in variety and net vulnerability of rice crop in PRECIS A2-2080 scenario in the Upper Ganga River Basin. The values below indicate percentage of current yields

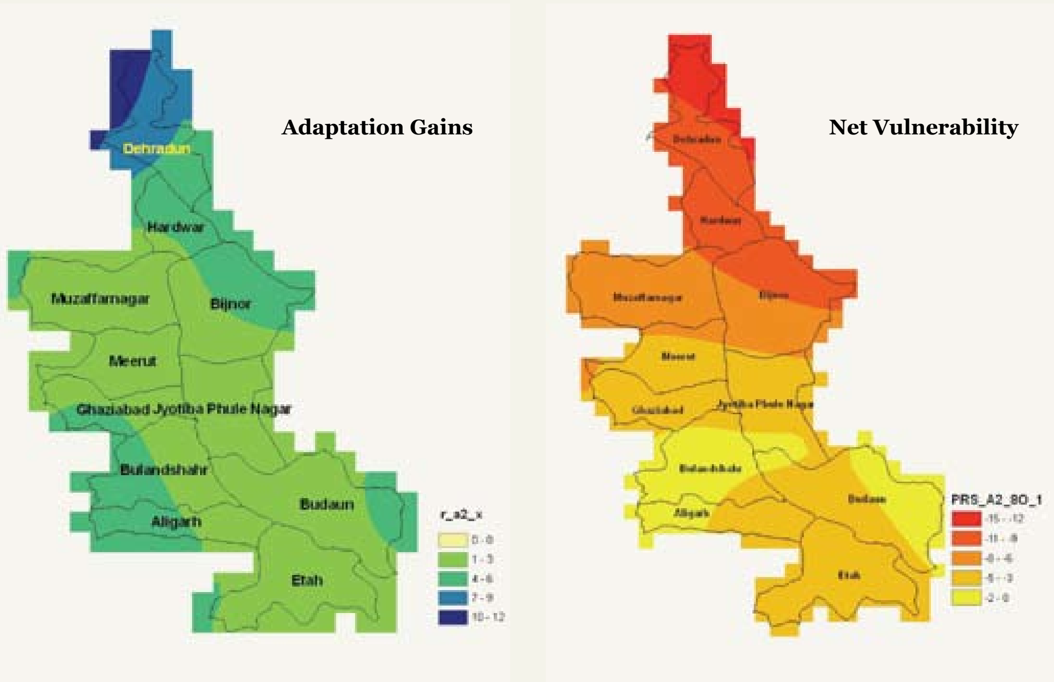
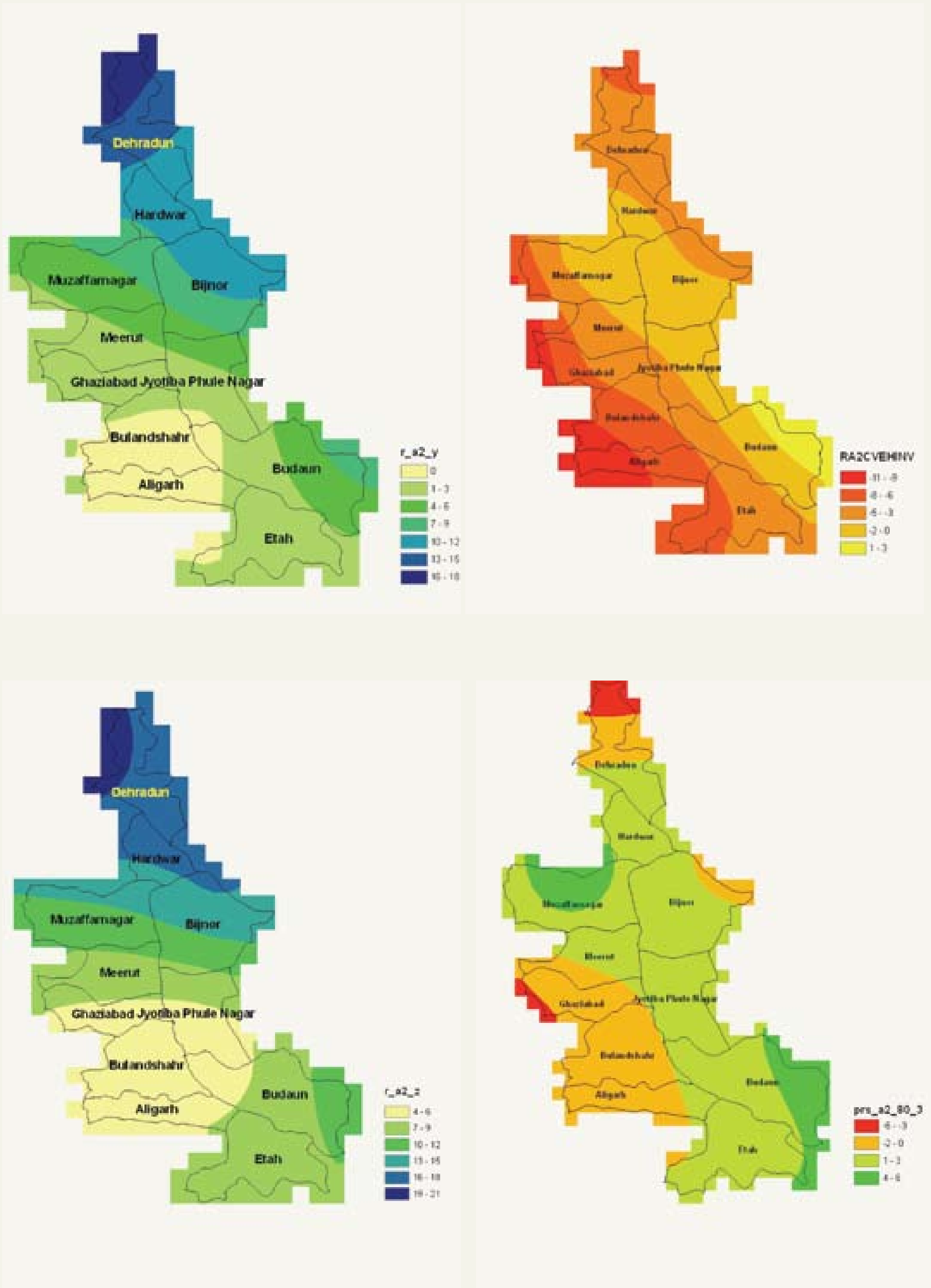


Figure 11 Adaptation gains due to a) current variety and better nitrogen and water management and b) improved variety and better nitrogen and water management with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for rice crop in PRECIS A2-2080 scenario in the Upper Ganga River Basin. The values below indicate the percentage of current yields

Adaptation Gains | **Net Vulnerability**

a)

b)



In order to further minimise the impacts, farmers will have to increase the efficiency of nitrogen and irrigation use. For this, even with current variety, better management of nitrogen and water to improve their use efficiency can be adapted. Nitrogen application and irrigation should be provided to suit the changed phenology of the crop in a changed environment. In this situation, the adaptation gains are projected to be up to 18% (Fig. 11). By adapting this strategy, the vulnerability of the area can be further reduced to 11%. However, if farmers grow improved variety, better manage fertiliser and irrigation water and provide additional but balanced fertilisers, the impacts of climate change in most parts of the region can almost be eliminated as far as A2-2080 scenario is concerned. In districts like Bulandshahr, Aligarh, Ghaziabad and Dehradun, the rice crop is projected to be vulnerable to climate change with a net vulnerability of up to 6%. With this adaptation strategy, rice crop in districts Etah, Baduan, JP Nagar, Bijnor, Haridwar, parts of Meerut and Dehradun is projected to benefit up to 6% of the current yields.

As far as B2-2080 scenario is concerned, a change in variety can bring adaptation gains up to 12% in the region. However, the region is still projected to remain vulnerable with a net vulnerability up to 10% (Fig. 12).

Similar to A2-2080 scenario, in order to further minimise the impacts in B2-2080 scenario, the farmers will have to increase the efficiency of nitrogen and irrigation use, even when they still continue to grow current varieties. In such a situation, the adaptation gains are projected to be up to 21%. By adopting this strategy alone, the vulnerability of the area can almost be eliminated. However, if the farmers grow improved variety with better management of irrigation and fertiliser and provide additional but balanced fertilisers, they are likely to harvest a higher yield up to 15%. These benefits are likely to be higher (10-15%) in the districts Etah, Baduan, Aligarh, JP Nagar, Bulandshahr and Ghaziabad. The northern districts are likely to be less benefitted (up to 6%) from such an adaptation strategy.

Figure 12

Adaptation gains due to change in variety and net vulnerability of rice crop in PRECIS B2 2080 scenario in Upper Ganga River Basin region. The values below indicate the percentage of current yields

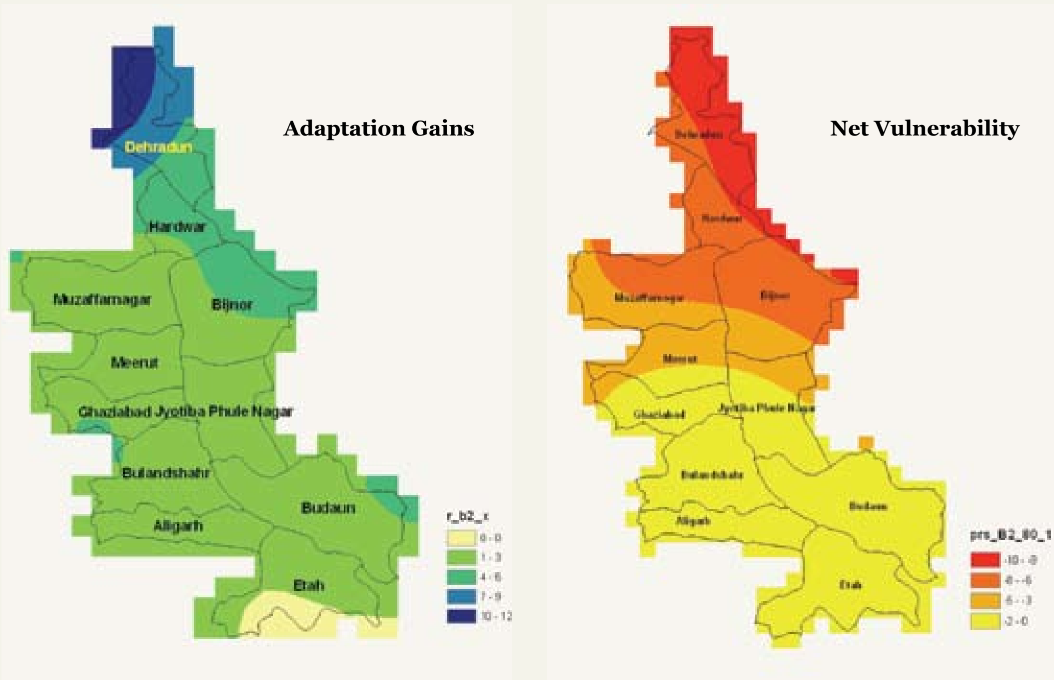


Figure 13

Adaptation gains due to a) current variety and better nitrogen and water management and b) improved variety and better nitrogen and water management with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for rice crop in PRECIS B2 2080 scenario in Upper Ganga River Bain region. The values below indicate the percentage of current yields

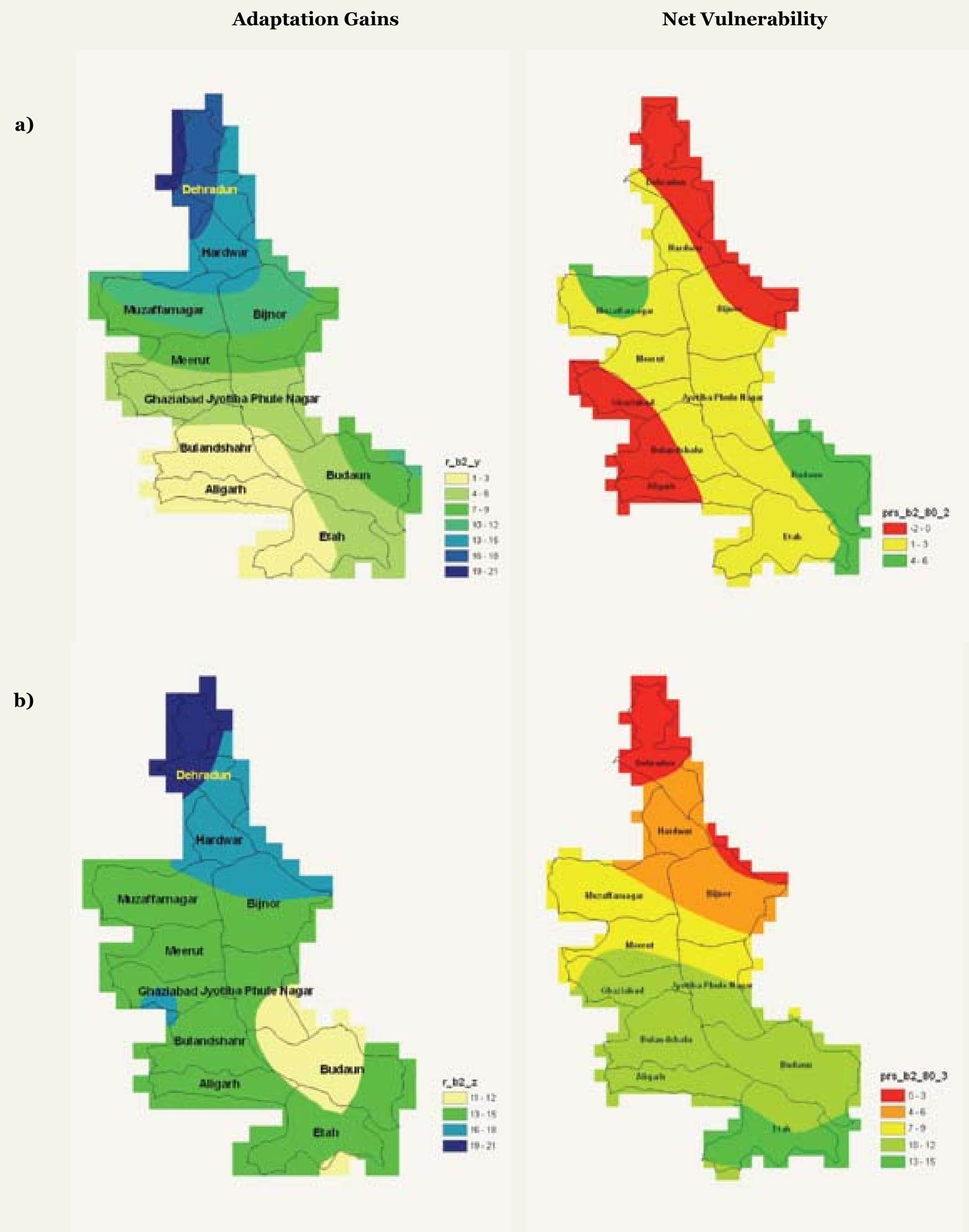


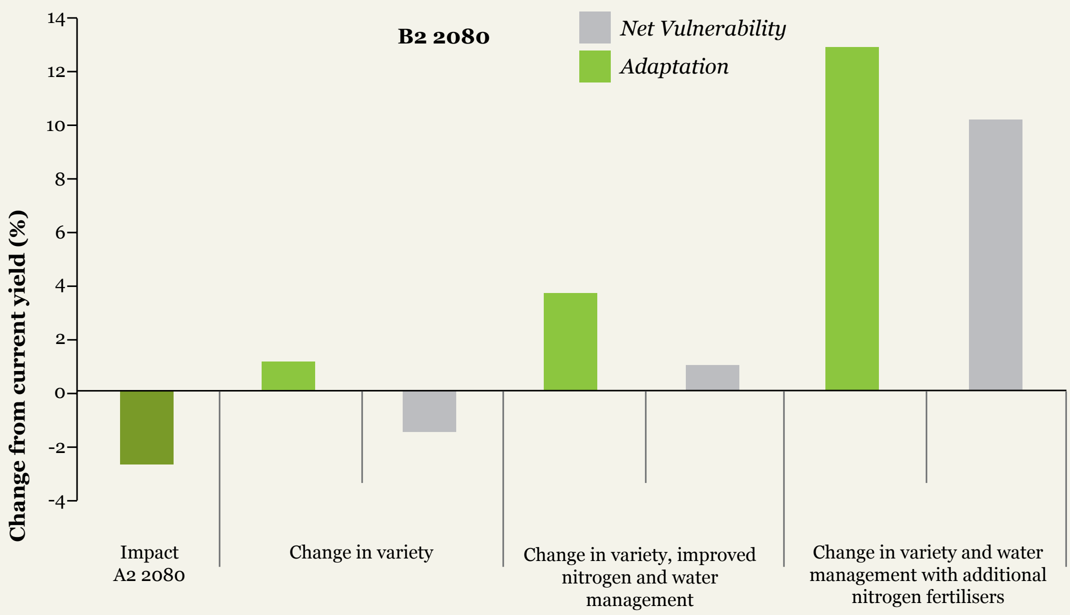
Table 3
Impact of climate change on paddy yields, adaptation strategies to reduce the impacts and net vulnerability of 11 districts in A2 and B2 scenarios of 2080 time scale

District	Impacts (% change from baseline yields)		Adaptation gains (% of current yield)						Net vulnerability (% of current yield)					
	A2 2080	B2 2080	A2 2080 Change in Variety	A2 2080 Current variety, improved management of nitrogen and water	A2 2080 Changed variety and water management with additional* nitrogen fertiliser	B2 2080 Change in Variety	B2 2080 Current variety, improved nitrogen and water management	B2 2080 Changed variety and water management with additional* nitrogen fertiliser	A2 2080	A2 2080	A2 2080	B2 2080	B2 2080	B2 2080
Aligarh	-5.33	-1.42	4.45	-0.00	5.72	1.29	2.28	11.63	-0.88	-5.33	0.39	-0.14	0.86	10.21
Bijnor	-2.91	-0.90	0.00	-0.00	3.99	0.00	3.37	11.24	-2.91	-2.91	1.08	-0.90	2.47	10.34
Badaun	-7.52	-1.29	2.65	-0.00	7.64	0.00	1.96	13.53	-4.87	-7.52	0.12	-1.29	0.67	12.24
Bulandshahr	-7.69	-4.57	4.37	-0.00	4.48	3.46	2.94	15.22	-3.32	-7.69	-3.21	-1.11	-1.63	10.65
Dehradun	-14.68	-12.26	4.35	11.42	14.83	4.09	11.48	15.51	-10.34	-3.26	0.15	-8.18	-0.79	3.24
Etah	-7.52	-1.29	2.65	-0.00	7.64	0.00	1.96	13.53	-4.87	-7.52	0.12	-1.29	0.67	12.24
Ghaziabad	-7.69	-4.57	4.37	-0.00	4.48	3.46	2.94	15.22	-3.32	-7.69	-3.21	-1.11	-1.63	10.65
Haridwar	-7.56	-7.53	0.00	5.00	11.76	0.92	11.49	14.08	-7.56	-2.56	4.20	-6.61	3.96	6.56
Jyotiba Phule Nagar	-2.91	-0.90	0.00	-0.00	3.99	0.00	3.37	11.24	-2.91	-2.91	1.08	-0.90	2.47	10.34
Meerut	-7.69	-4.57	4.37	-0.00	4.48	3.46	2.94	15.22	-3.32	-7.69	-3.21	-1.11	-1.63	10.65
Muzaffarnagar	-7.56	-7.53	0.00	5.00	11.76	0.92	11.49	14.08	-7.56	-2.56	4.20	-6.61	3.96	6.56

* Additional Nitrogen in balance with other nutrients. Particularly applicable to farmers applying lesser dose of fertilisers

Figure 14

Adaptation gains due to a) improved variety b) current variety with better nitrogen and water management and c) improved variety and better management of nitrogen and water with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for rice crop in PRECIS A2 and B2 2080 scenarios in Upper Ganga River Basin region



The district-wise impacts, adaptation and net vulnerability are provided in Table 3. The analysis projected that change in variety alone can make farmers better equipped to face the climate change impacts on rice crop. If the farmers continue to use current varieties and adapt better management of nitrogen and water, then the adaptation benefits may only be realised in districts like Dehradun, Haridwar and Muzaffarnagar in A2-2080 scenario. But in B2-2080 scenario, this kind of adaptation can benefit the crop in all but three districts. However, improved variety, better management of nitrogen and water and increased nitrogen application is projected to benefit the rice crop in this region even under climate change scenarios. Even after all these adaptations, the rice crop in Bulandshahr, Ghaziabad and Meerut is vulnerable to climate change. It may be noted that the application of additional nitrogen is particularly in the context of farmers who are applying less than the recommended dose of fertiliser. Also, in the future climate scenarios, an increased loss of nitrogen due to volatilisation and other factors like additional but balanced fertiliser input is anticipated. This also helps in reaping the benefits of carbon fertilisation effects.

Quantification of the impact of climate change on wheat

Wheat yields are projected to be affected by climate change in this region. The impacts are projected to be more in A2 scenario than in B2 scenario. The loss is projected to be higher in Badaun, Etah, Aligarh, Bulandsahahr, Ghaziabad, Meerut, JP Nagar and Muzaffarnagar with approximately 20% loss in PRECIS A2 2080 and up to 6% loss in PRECIS B2 2080 scenario. In the north-eastern parts of Meerut, JP Nagar and Muzaffarnagar districts, the losses may be lesser in A2 (up to 8%) scenario, whereas in B2 scenario, wheat yields in these areas are projected to benefit up to 8% (Fig. 15). In Dehradun, Haridwar and Bijnor wheat yields are projected to increase up to 18% in climate change scenarios. However, the southern part of Bijnor is likely to face yield loss up to 8% in A2 scenario. These results indicate that climate change is likely to affect the wheat yields in nine out of 11 districts under consideration.

Projected yield change in irrigated wheat due to climate change in 11 districts of study area under PRECIS A2 and B2-2080 scenarios. Relative yield change (% deviation) is from the current yields

Figure 15

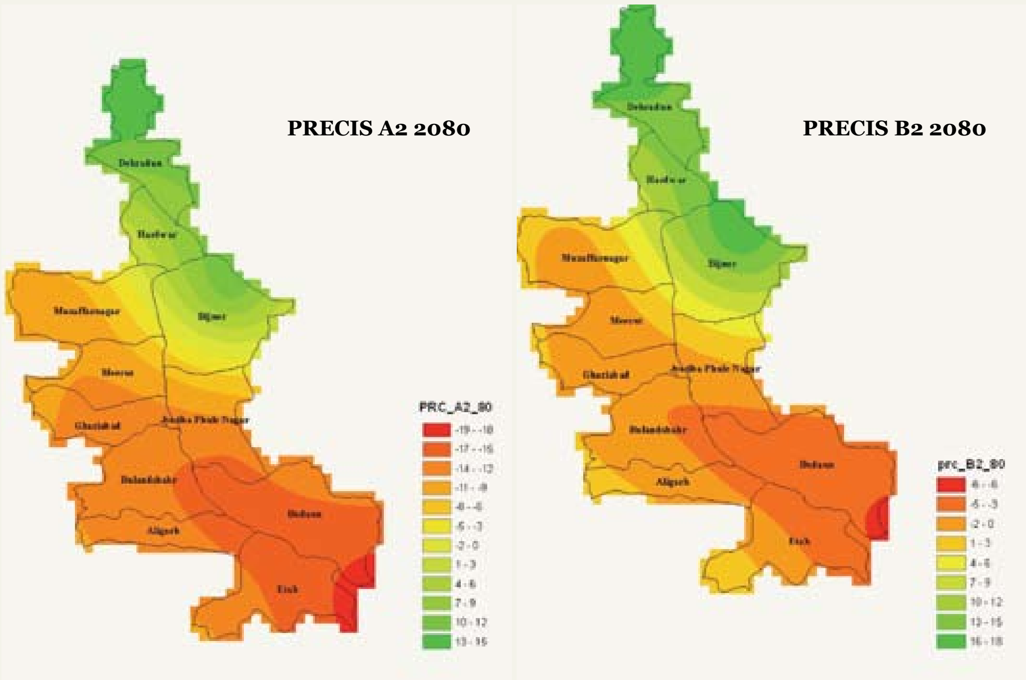
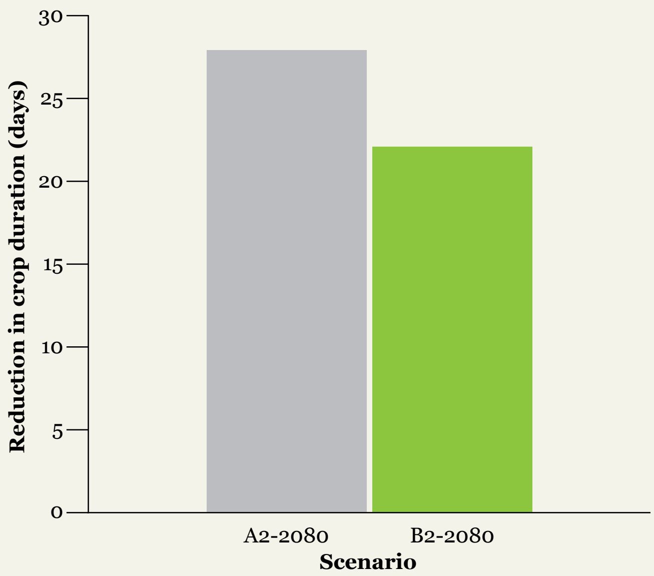


Figure 16 Projected probability of reduction in crop duration in the study area under PRECIS A2 and B2-2080 scenarios. The changes are relative to those of the baseline period of 1969-1990



The analysis indicated that climate change in 2080 scenarios projected to reduce the crop duration by 28 days (A2) and 22 days (B2) in the region (Fig. 16). However, spatial variations exist for the extent of reduction in crop duration. As a result of reduction in crop duration, the grain yield also is projected to be affected.

Strategies for adapting wheat to climate change

Climate change is projected to affect wheat yields in eight of the 11 districts but is likely to benefit the crop in three districts. In order to minimise the adverse impacts and maximise the beneficial effects, a simulation analysis was done to find the low-cost adaptation strategies involving improved variety, improved fertiliser and irrigation management, change in sowing time, increased seed replacement by the farmers and increased fertiliser application. A combination of these was put into the model and it was run for climate change scenarios to identify alternate suitable adaptation combinations. The results indicated that a change in variety alone is likely to improve the yields up to 5% in the region. In 90% of the area, the yield benefits are projected to be less than 3%. Hence further adaptation options were worked out to minimise the impacts.

Sowing of improved variety with better management of fertiliser and irrigation application can improve the yield up to 9% in A2-2080 climate change scenario (Fig. 17). Such gains are likely to be higher in parts where climate change is projected to adversely impact the wheat yields. However, projected net vulnerability of region is still projected to be up to 15%.

Figure 17 Adaptation gains due to change in variety and net vulnerability of wheat crop in PRECIS A2-2080 scenario in the Upper Ganga River Basin. These values are the percentage of current yields

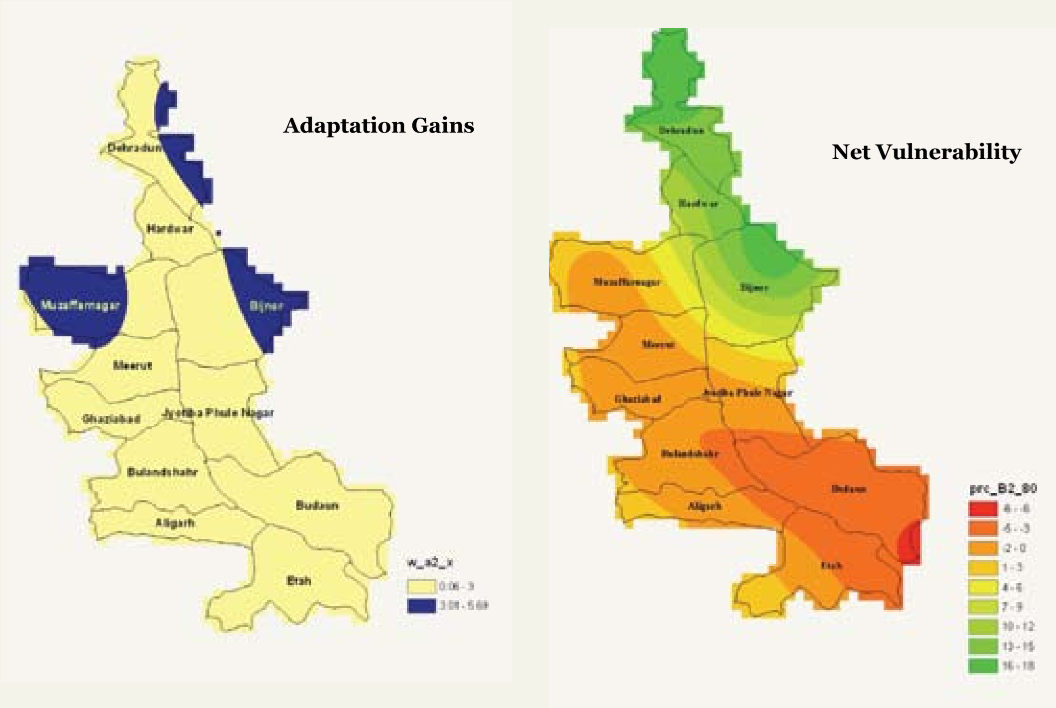


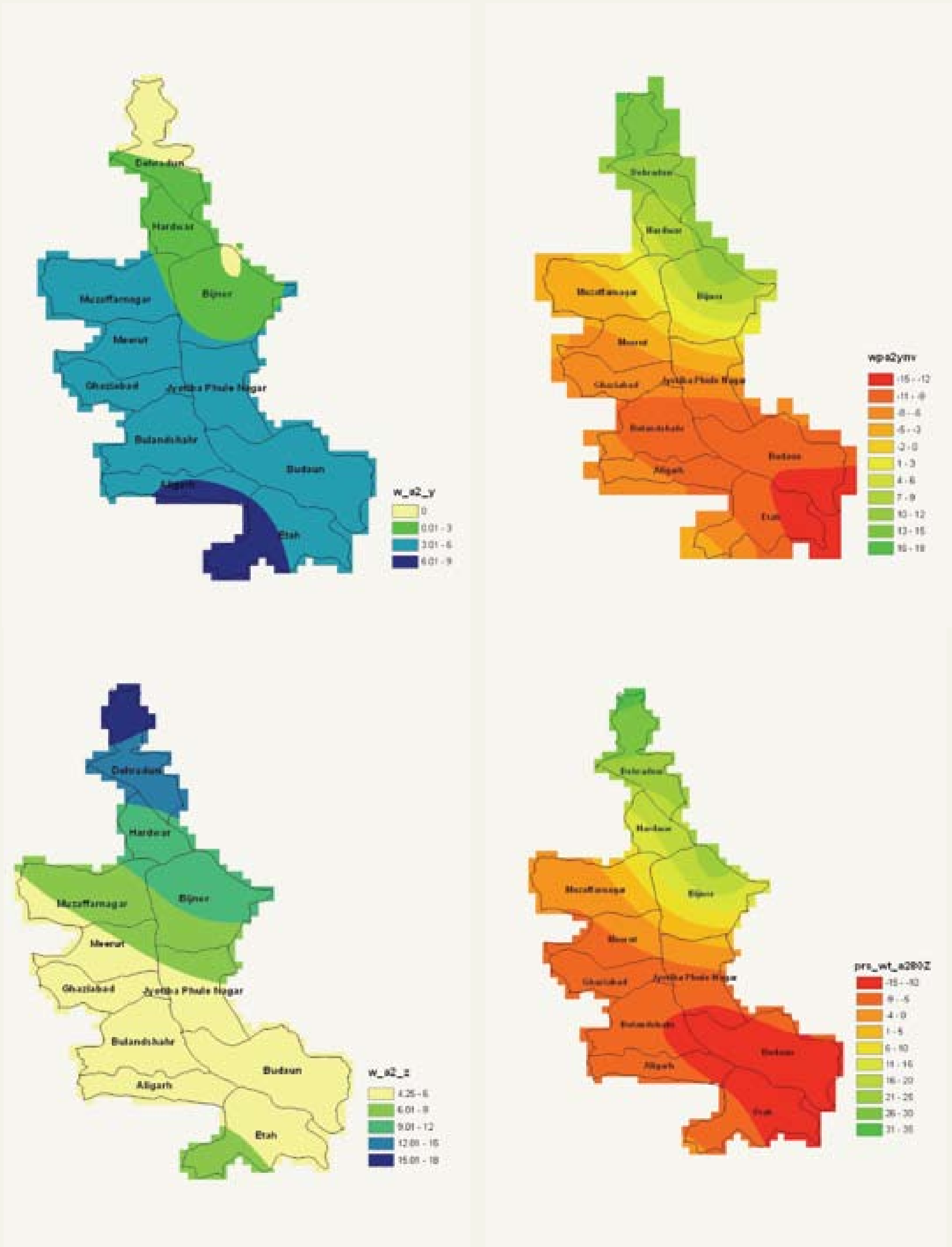
Figure 18

Adaptation gains due to a) improved variety and better management of nitrogen and water and b) improved variety and better nitrogen and water management with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for wheat crop in PRECIS A2-2080 scenario in the Upper Ganga River Basin

Adaptation Gains | **Net Vulnerability**

a)

b)

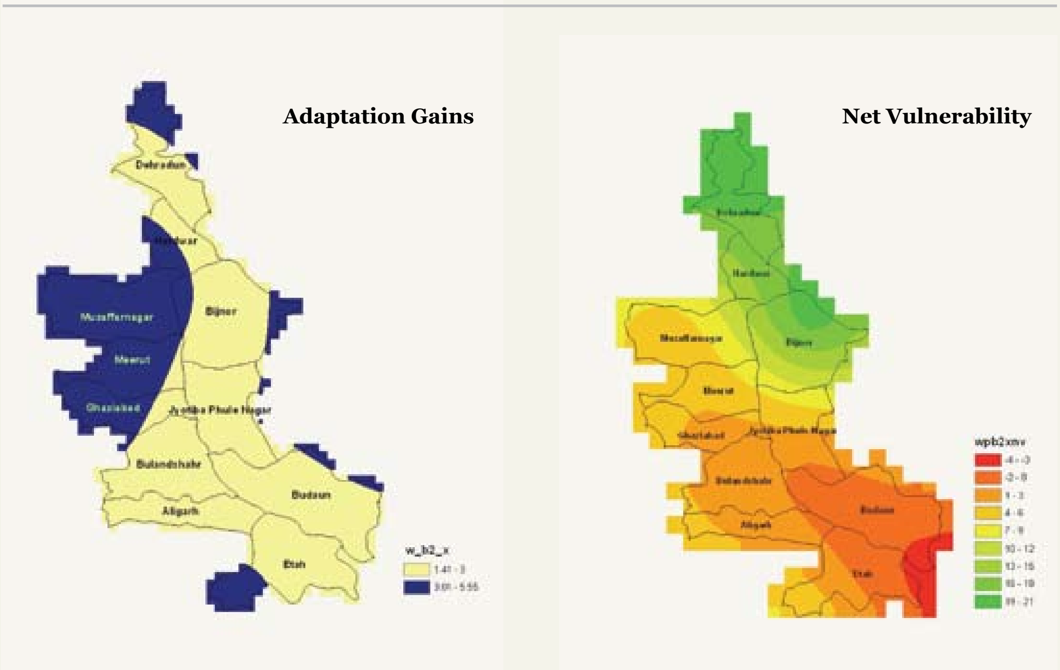


In addition to the above adaptation strategies, if farmers provide additional nitrogen, in balance with other nutrients, the adaptation gains in yield is likely to be increased to 16%, thus one can bring down not only the net vulnerability of wheat crop in the region but also reduce the area under high vulnerability (Fig. 18).

As far as the B2-2080 scenario is concerned (Fig. 19), adaptation gains due to change in variety are almost similar to those under A2 scenario. Since the impacts are likely to be less in B2 scenario, a change in variety alone can substantially reduce the impacts and thus net vulnerability of wheat. In fact, by adapting this strategy, the whole region can be benefitted, nullifying the impact of climate change except two districts viz., Baduan and Etah, where net vulnerability is projected to be around 4% even after adapting the improved variety.

Figure 19

Adaptation gains due to change in variety and net vulnerability of wheat crop in PRECIS B2-2080 scenario in the Upper Ganga River Basin. These values are a percentage of current yields



However, by adapting improved variety, better management of fertiliser and irrigation, the farmers not only offset the entire climate change (B2-2080) impacts but also can reap higher harvests (Fig. 19). Providing additional nitrogen, in balance with other nutrients may further enhance the output. However, spatial variations for gains are likely to exist with the northern part of the region gaining more (up to 45%) than the southern part (up to 9%).

Figure 20

Adaptation gains due to a) improved variety and better nitrogen and water management and b) improved variety and better nitrogen and water management with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for wheat crop in PRECIS B2-2080 scenario in the Upper Ganga River Basin. These values are a percentage of current yields

Adaptation Gains **Net Vulnerability**

a)

b)

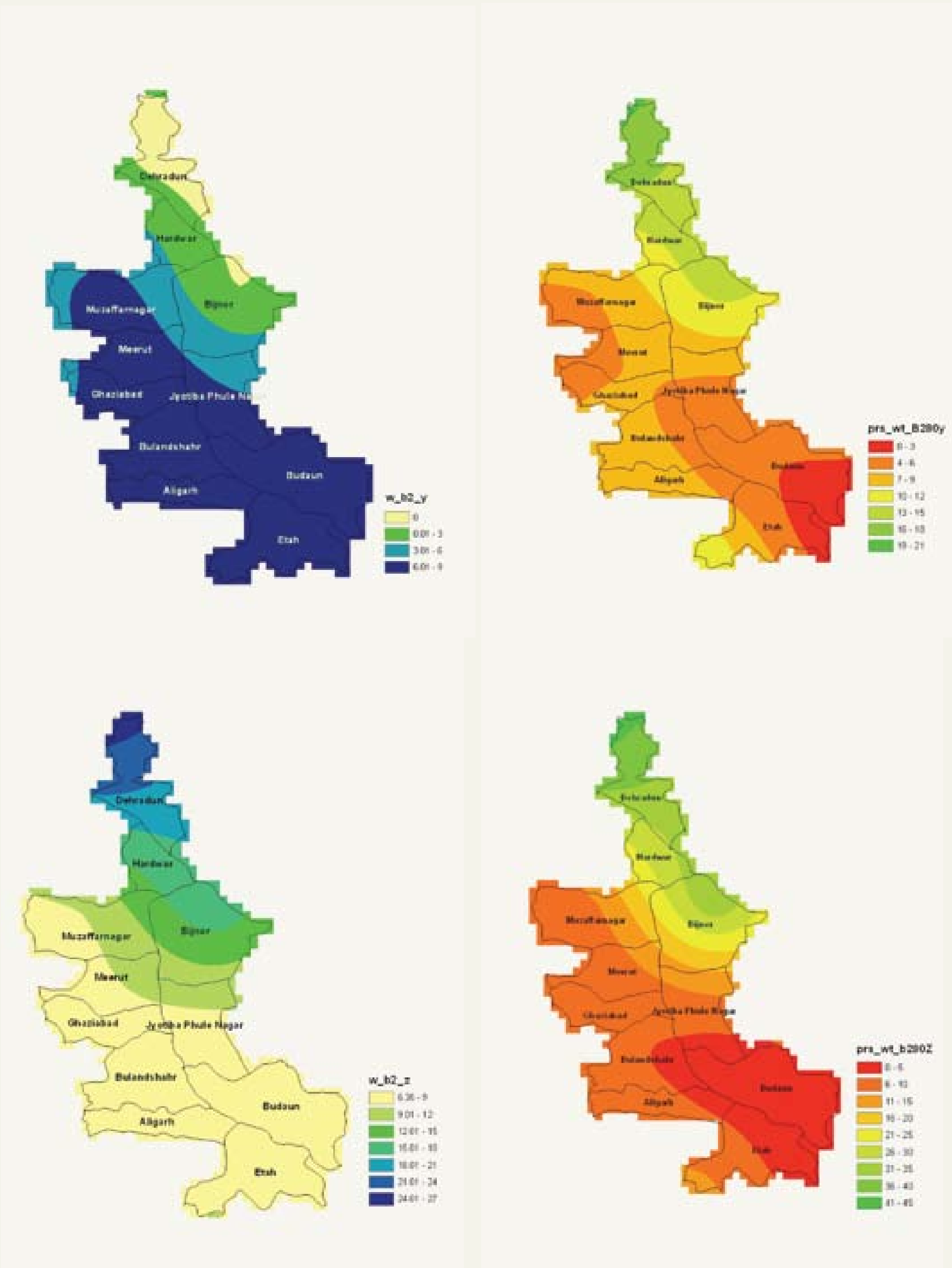
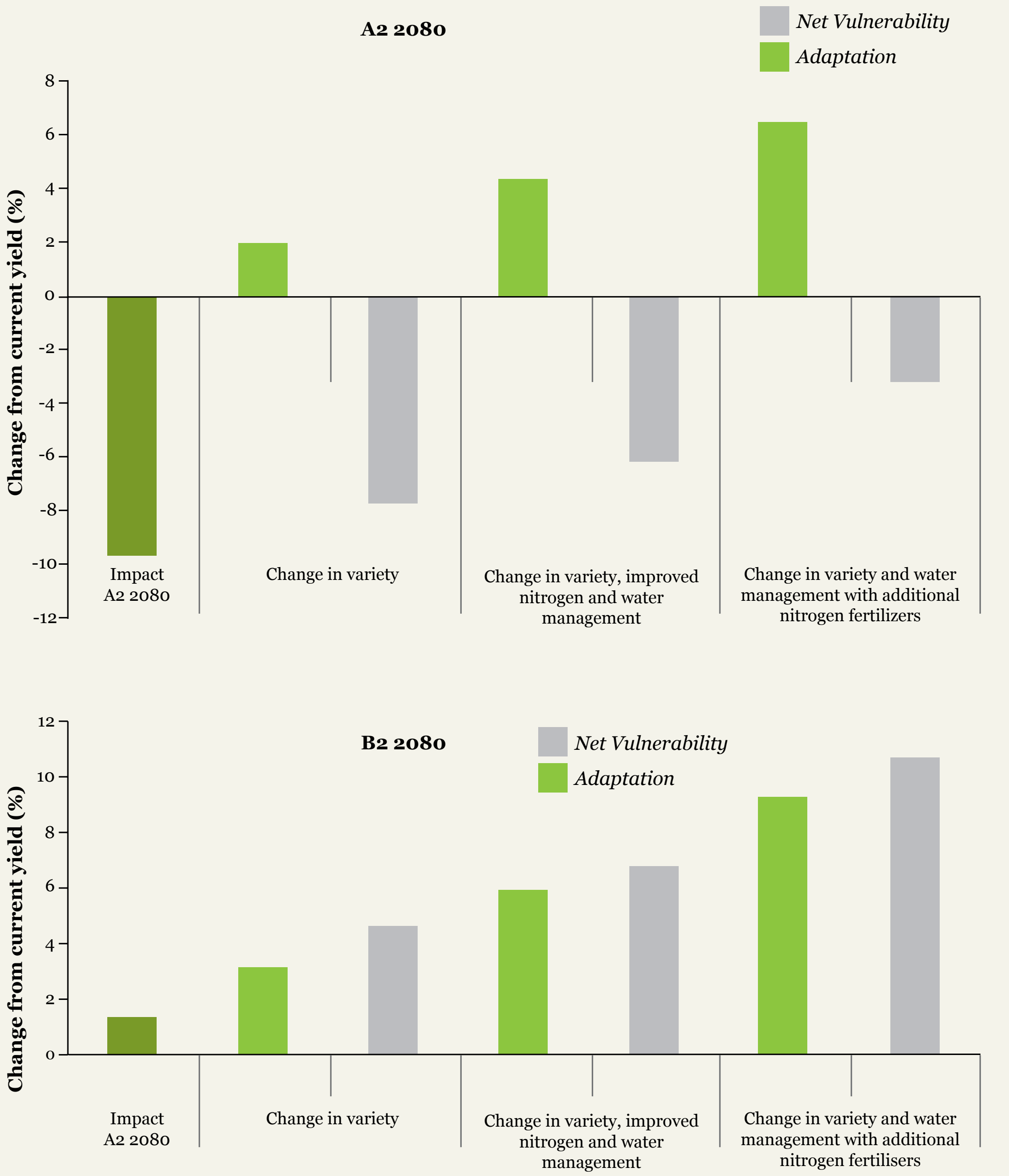


Figure 21

Adaptation gains due to a) improved variety b) improved variety with better nitrogen and water management and c) improved variety and better nitrogen and water management with additional nitrogen fertiliser and net vulnerability in respective adaptation situations for wheat crop in PRECIS A2-2080 and B2-2080 scenarios in the Upper Ganga River Basin



The bar diagrams in Fig. 21 indicate that by changing variety and with better management of water and fertilisers, the impacts of climate change can be minimised in the study region in A2 scenario. Slight negative impacts in B2 scenario can be nullified by adaptation and even improvement of yields as compared to the current yields is likely to benefit to the tune of 10%. In A2 scenario, the crop production is likely to be around 4% lesser in spite of the adaptations mentioned. An explanation regarding additional fertilisers for reaping better harvests under future climate scenarios has already been provided earlier.

Table 4
Impact of climate change on wheat yields, adaptation strategies to reduce the impacts and net vulnerability of 11 districts in A2 and B2 scenarios of 2080 time scale

District	Impacts (% change from baseline yields)		Adaptation gains (% of current yield)						Net vulnerability (% of current yield)					
	A2 2080	B2 2080	A2 2080 Change in Variety	A2 2080 Current variety, improved management of nitrogen and water	A2 2080 Changed variety and water management with additional* nitrogen fertiliser	B2 2080 Change in Variety	B2 2080 Current variety, improved nitrogen and water management	B2 2080 Changed variety and water management with additional* nitrogen fertiliser	A2 2080	A2 2080	A2 2080	B2 2080	B2 2080	B2 2080
Aligarh	-12.51	0.55	1.49	5.48	5.6	2.93	7.22	7.56	-11.02	-7.03	-6.91	3.48	7.77	8.11
Bijnor	-2.17	7.12	2.44	2.46	8.13	2.61	3.43	11.95	0.28	-2.32	5.97	9.72	8.63	19.06
Badaun	-14.93	-2.71	1.16	5.39	5.54	3.27	7.39	7.76	-13.77	-9.54	-9.39	0.55	4.68	5.04
Bulandshahr	-13.95	-1.95	1.62	4.69	4.83	3.46	7.31	7.78	-12.33	-9.26	-9.11	1.51	5.36	5.83
Dehra Dun	11.23	15.56	3.63	0	13.29	3.13	0.4	19.61	14.86	7.94	24.51	18.69	14.68	35.17
Etah	-16.73	-3.09	0.49	5.64	5.72	2.55	7.44	7.6	-16.24	-11.09	-11.01	-0.53	4.35	4.51
Ghaziabad	-13.95	-1.95	1.62	4.69	4.83	3.46	7.31	7.78	-12.33	-9.26	-9.11	1.51	5.36	5.83
Haridwar	5.89	11.51	3.8	1.6	11.7	3.73	2.03	16.91	9.69	5.03	17.6	15.24	12.58	28.41
Jyotiba Phule Nagar	-2.17	7.12	2.44	2.46	8.13	2.61	3.43	11.95	0.28	-2.32	5.97	9.72	8.63	19.06
Meerut	-6.87	3.1	2.73	3.94	6.96	3.72	5.39	10.21	-4.14	-4.23	0.09	6.82	7.53	13.32
Muzaffarnagar	0.21	8.16	3.83	3.2	9.09	3.98	3.46	12.65	4.04	0.8	9.3	12.13	9.7	20.8

* Additional nitrogen in balance with other nutrients. Particularly applicable to farmers applying lesser dose of fertilisers.

The district-wise analysis indicated that in the A2 scenario, Aligarh, Badaun, Bulandshahr, Etah and Ghaziabad districts are vulnerable to climate change in spite of adaptation measures. District Meerut can barely overcome the impact of climate change by following the adaptation measures. On the other hand, in the B2 scenario none of the districts are likely to fall under the vulnerable category. In this scenario, wheat is projected to gain with adaptation measures with an increase in production by about 11%.

5.0 CONCLUSION & RECOMMENDATIONS

Climate change is projected to adversely influence the crop production in India. Analysis of future climate scenarios in 11 districts of the Upper Ganga River Basin indicated spatial and temporal variation for changes in temperature and rainfall. Simulation analysis carried out for the quantification of the climate change impacts on rice-wheat system and for suggesting low-cost adaptation strategies in these areas, projects varied impacts on growth and yield of rice and wheat during *Rabi* and *Kharif* seasons in A2 and B2 2080 scenarios of climate.

Climate change is projected to increase the temperatures more in the A2 scenario than in the B2 scenario. The projected increase in temperature is relatively higher during the *Rabi* season than in the *Kharif* season. Temperatures are projected to increase more in areas which are currently warmer. An increase in temperature is likely to be relatively less in the hilly areas of Dehradun, Haridwar and Bijnor. *Kharif* rainfall is projected to significantly increase in the north and north-east parts of the study region whereas *Rabi* rainfall is projected to increase marginally in the south and eastern parts of the study area.

Simulation studies conducted using InfoCrop-Wheat and InfoCrop-Rice models, indicate that rice and wheat crops are likely to be affected more in the A2 scenario than in the B2 scenario. Climate change is likely to benefit wheat crop in northern parts of the study region in districts Dehradun, Bijnor, Haridwar, JP Nagar and Muzaffarnagar. On the other hand, rice crop in the north of the study region is likely to be more affected by climate change as compared to the southern region.

Low-cost adaptation strategies

Simulation analysis for developing strategies for adapting rice to climate change scenarios emphasised low-cost adaptation strategies which included improved crop variety, change in variety and improved crop management, change in sowing time, efficient utilisation of irrigation and fertiliser, increased seed replacement by the farmers and increased fertiliser application. Farmers will be in a position to reduce their net vulnerability, if they follow one of the low-cost adaptation strategies in both A2-2080 and B2-2080 scenarios.

Simulation analysis for finding low-cost adaptation strategies for wheat indicated that while change in variety alone is likely to improve the yields in A2-2080 scenario, sowing of improved variety with better management of fertiliser and irrigation application can further enhance the yield. With the provision of additional nitrogen, in balance with other nutrients, the adaptation gains in yield is likely to be much higher, bringing down the net vulnerability of wheat crop in the region but also reducing the area under high vulnerability.

Since the impacts are likely to be less in B2 scenario, a change in variety alone can substantially reduce the impacts and thus net vulnerability of wheat. However, by adapting improved variety, better management of fertiliser and irrigation, the farmers not only offset the entire climate change (B2-2080) impacts but can also reap higher harvests. Together with the provision of additional nitrogen, in balance with other nutrients may further enhance the output.

In general, inspite of the adaptation strategies, some parts of the region (southern parts for wheat and western and northern hilly parts for rice) may still be vulnerable under the A2 scenario. Hence, it is important to devise a comprehensive 'no regret' adaptation strategy to overcome the adverse impacts of climate change.

Strategy	A2-2080	B2-2080
Rice		
• Change in variety	• Maximum gain likely to be upto 12% • Projected gains for most parts of the study region upto 3%	• Maximum gain likely to be upto 12% • Projected gains for most parts of the study region lie in the range of 1- 3%
• Better management of nitrogen and water with current variety	• Gains due to this strategy can be upto 18% • Projected gains for the study region ranges from 1- 6% with progressive increase from South to North	• Maximum gains upto 21% • Projected gains for most parts of the study region lie in the range of 2-4%
• Improved variety and better nitrogen and water management with additional nitrogen fertiliser	• Most beneficial strategy as it can yield benefits upto 21% • Most parts of the study region likely to have projected gains above 7%	• Adaptation benefits upto 15% • Most beneficial strategy for the study region as 11 -15% benefits projected for the complete study region
Wheat		
• Change in variety	• The strategy can yield benefits upto 5% • Yield benefits projected to be less than 3% in most parts of the study region	• Maximum yield gains expected upto 5% • Yield benefits between 1-3% expected in the study region
• Improved variety with better management of nitrogen and water	• Maximum benefits expected upto 9% • Most areas of the study region likely to have gains in the range of 3-6% with progressive decrease towards the northern region	• Adaptation gains can be upto 9% • 3- 9% gains expected for most parts of the study region
• Improved variety and better nitrogen and water management with additional nitrogen fertiliser	• Maximum increase likely to be upto 18% • 4-9% of gains expected in most parts of the study region	• Most parts of the study region likely to get 6 -12% gains however the maximum limit expected is upto 27%

No-regret adaptation strategies

Developing adaptation strategies exclusively for minimising the negative impact of climate change may be risky considering the number of uncertainties associated with its spatial and temporal magnitude. We need to identify 'no-regret' adaptation strategies that may anyway be needed for sustainable development of agriculture in the region. These adaptations can be at the level of individual farmer, farm, society, village, watershed or even at a national level.

Simple adaptation strategies such as a change in the planting date and variety further reduced the extent of loss caused by high temperature as mentioned earlier. Adaptation strategies can assist in providing some relief in future provided these strategies could be operationalised in field. Possible adaptation options include:

- Augmenting production by improved crop management, improved/adverse climate tolerant varieties, improved seed sector, technology dissemination mechanisms, capital and information, the lack of which are some of the key reasons for yield gaps.
- The watershed management programme can yield multiple benefits. Such strategies could be very useful in future climatic stress conditions.

- Conservation agriculture is one of the most important strategies for combating climate change adverse impacts.
- Increasing the income from agricultural enterprises by suitable actions such as accelerated development of location-specific fertiliser practices, improved fertiliser supply and distribution system, improved water and fertiliser use.
- Improved risk management through an early warning system and policies that encourage crop insurance can provide protection to the farmers if their farm production is reduced due to natural calamities. Use of information technology could greatly facilitate this. An early warning system for pest and disease incidence will be highly helpful.
- Recycling waste water and solid wastes in agriculture since fresh water supplies are limited and has competing uses, and would become even more constrained in changed global climate. Industrial and sewage wastewater, once properly treated can also be a source of irrigation for crops. Since water serves multiple uses and users, an effective inter-departmental co-ordination within the government is required to develop the location-specific framework of sustainable water management and optimum recycling of water.
- Harvest and post-harvest management for minimising the losses due to extreme climatic events or mean climate change conditions. Providing community-based post harvest storage spaces at village level can help the farmer to save the produce from exposure to any climate related extreme event. Research efforts are required to design the storage structures and efficient processes for changed climate.

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