Chapter 6
Addressing the Potential Impacts of Climate Change and Variability on Agricultural Crops and Water Resources in Pennar River Basin of Andhra Pradesh

Sridhar Gummadi and K.P.C. Rao

Abstract The objective of the current study is to address the possible potential impacts of climate change and variability on agricultural crops and water resources in Pennar river basin, of Southern India. As part of the study Integrated Modelling Assessment (IMS) was developed by establishing functional links between hydrological model Soil Water Assessment Tool (SWAT), agricultural crop simulation model Environmental Policy Integrated Climate (EPIC) and regional climate model Providing REgional Climates for Impacts Studies (PRECIS). Database pertaining to climatic parameters, hydrological and agro-meteorological inputs to run integrated assessment systems are synthesized to run the model for study area. The model in general aim at major driver of this study is HadRM3 (Hadley Centre third generation regional climate model)—The Hadley Center Regional Climate Models resolution, which is 0.44° × 0.44° (approx. 50 km cell–size) on ground covering an average size of typical Indian districts/sub-basins. For regional levels the results are obtained by aggregating from the sub-basin/district level. The assessment will include the following components: (1) Baseline climatology, (2) Under global warning HadRM3 derived climate change scenarios, (3) Water Resources (Hydrological) analysis including irrigation water, and (4) agro-meteorological analysis including soil-water regime, plant growth and cropping pattern. Overall in Pennar region results revealed that the mean annual flows in the river system would increase by 8 % in A2 and 4 % in B2 whereas, increase in evapotranspiration losses were found to be about 10 % in A2 and 12 % in B2. Impacts on crop yields is the combined effect of increased surface temperatures, decreased rainfall and higher ambient atmospheric CO_2. Three rain-fed crops (Groundnut, Sorghum, Sunflower) show decreased yields under A2, whereas B2 seemed to be relatively better than A2. The decrease is significant for groundnut (−38 % for A2

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and −20 % for B2), but compared to groundnut impact were less detrimental for other two rain-fed crops (Sorghum and Sunflower). Rice being an irrigated crop in the region showed decrease in yield by −15 and −7 % for A2 and B2 scenarios respectively. Negative simulated crop yields in the region are predominantly due to increased surface temperatures in the future climate change scenarios.

Keywords Climate change · SWAT · EPIC · PRECIS

Introduction

Potential impacts of climate change on agricultural crops and water resources has utmost importance in tropical countries like India due to continues crop failures and shortage of water for domestic, industrial and agricultural purpose. It is well understood from the recent past studies that agricultural crops are most vulnerable to changes in weather and climate (Slingo et al. 2005; Osborne et al. 2007; Challinor and Wheeler 2008; Schlenker and Roberts 2008).

Agriculture is the backbone of India's economy and is highly dependent on the spatial and temporal distribution of monsoon rainfall. Much of the country relies on tropical monsoons for approximately 80 % of the annual rainfall and most of this falls within 3–4 months (Mitra et al. 2002). For most parts of India, this major proportion falls during the summer (June–September) monsoon season. The temporal and spatial variations of the Indian summer monsoon have great relevance in the context of agriculture, industrial development, and planning and policy formulation. The agriculture sector is expected to be significantly affected by a reduction in crop water availability and an increase in the probability of extreme weather events resulting from the combined influence of elevated CO_2 concentrations and rise in surface temperatures (Chiotti and Johnston 1995).

Addressing the impacts of climate change on agricultural crops and water resources are often based on dynamic crop, hydrological and climate simulations models. Simulation models are computer based representations of physiological process responsible for plant growth and development, evapotranspiration and partitioning of photosynthetic output to produce economic yield (Crop models) (Boote et al. 1998; Williams 1995; Challinor et al. 2005), hydrological models are physical process based models represent complex surface runoff, subsurface flow, channel flow and evapotranspiration (Arnold et al. 1998; Harding et al. 2012), Climate models are based on well-established physical principles and have been demonstrated to reproduce observed features of recent and past climate changes (Houghton et al. 2001; Gnanadesikan et al. 2006). General Circulation Models (GCMs) and Regional Circulation Models (RCMs) are the most effective approach to explore the processes in the atmosphere, ocean and land surface. Global climate models provide the starting point for construction of the current and projected changes in future climate due to the increased anthropogenic emissions. The coupled atmosphere-ocean general circulation models (AOGCMs) have become the best available tools in addressing and understanding future climate change projections (Houghton et al. 2001). The basic climate models (GCMs) are coupled with atmosphere (A) and ocean and sea-ice (O). The complex equations are solved using a 3D grid over the Earth's surface. The 21st century climate models have 5 major components of Earth's system atmosphere, ocean, land surface, cryosphere (sea ice, snow) and biosphere.

This study focuses on the projected changes in future climate and its impacts on water resources and agricultural crops grown in Pennar watershed of Andhra Pradesh, India. Although studies on the impacts of climate change and variability on agricultural productivity have been conducted at global and national levels, only a few studies have focused on the integrated impacts of climate change on agricultural crops and water resources. This study aims to investigate the potential impacts of climate on available water resources and agricultural crops using hydrological model (SWAT), agricultural model (EPIC) and regional climate model (PRECIS):

1. Evaluating the ability of existing crop (EPIC) and hydrological (SWAT) models in the study area to simulate current climate variability
2. To study the response of mean changes in future climate on crop production and surface flow in Pennar river basin and
3. Developing strategic adaptation measures in response to the negative impacts of climate in the study area

Materials and Methods

Site Description

The study is conducted in Pennar basin in Andhra Pradesh state of India. Pennar Basin extends over an area of 55,213 km^2, which is nearly 1.7 % of total geographical area of the country. The basin lies in the states of Andhra Pradesh (48,276 km^2) and Karnataka (6,937 km^2). Pennar River rises from the Chenna Kesava hills of the Nandi ranges of Karnataka and flows for about 597 km before out falling into Bay of Bengal. The principal tributaries of the river are the Jayamangal, the Kunderu, the Sagileru, the Chitravati, the Papagni and the Cheyyeru. The important soil types found in the basin are red soils, black soil, sandy soil and mixed soil.

It is generally flat, having mostly slopes of less than 6.5 %. The basin is divided into 58 sub-basins covering four districts namely Kurnool, Ananthpur, Cuddapah and Chiitor comprises 160 Mandals (district sub-units). This study is conducted for all the Mandals of above mentioned four district and sub-basin as shown in the Fig. 6.1 Study area is located between, 77.10–80.15°E and 13.3–15.8°N.

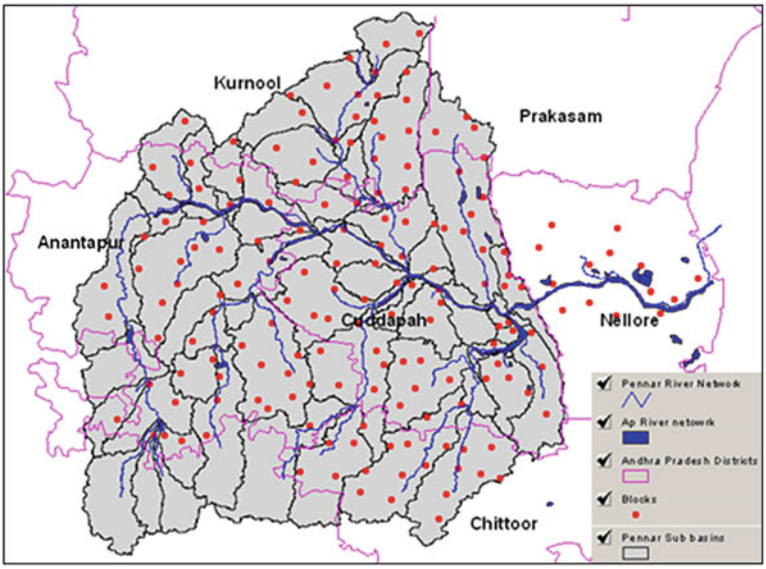

Fig. 6.1 Pennar basin—Andhra Pradesh, India

Digital Elevation Model (DEM)—DEM represents a topographic surface in terms of a set of elevation values measured at a finite number of points. Shuttle Radar Topography Mission (SRTM) ~90 m resolution DEM has been used for the study. Drainage relief, river network and rainfall stations of study area are shown in Fig. 6.2.

Climate is predominately semi-arid to arid. In general, there are four seasons in this region. Hot weather (from March to May), Southwest monsoon (from June to September), Northeast monsoon (from October to December) and winter (from

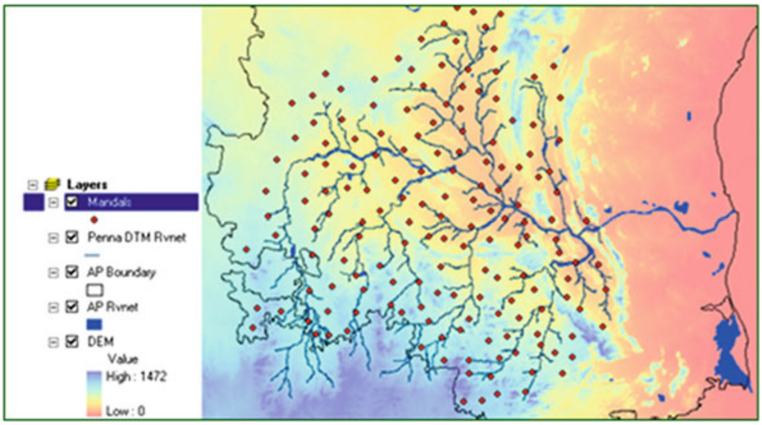

Fig. 6.2 Drainage and relief in Pennar basin, Andhra Pradesh

December to February). The state of Andhra Pradesh is divided into seven zones based on the agro-climatic conditions. The classification mainly concentrates on the range of rainfall received, type of the soils and topography. Study region falls in Rayalseema region including Ananthpur, Chittor, Cuddapah and Kurnool districts and parts of Prakasam and Karnataka state.

Climate data required by the models are daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. These daily climatic inputs are entered from historical records in the model using monthly climate statistics that are based on long-term weather records. In this study, historical precipitation and temperature records for Pennar basin are obtained for 4 Indian Meteorological Department (IMD) weather stations located in and around the watershed are used for the current study. Stations Names are Kurnool, Anantapur, Cuddapah and Chittor in which the study area lies. Rayalaseema zone is in the semi-arid track. It receives an average annual rainfall in the range of 500–1,000 mm. Most of which come from southwest monsoon and the northeast monsoon. The rains normally begin in the second week of June and lasts till September (Southwest monsoon), which marks the main growing season (locally known as *Kharif*).

Results

Model Evaluation

Hydrological Model—SWAT

SWAT hydrological model is validated and calibrated over a 15-year period (1988–2003) by using historical climate data and comparing simulated output with the observed stream flows measured at four gauge stations in the basin. SWAT simulation methodology consist of an initial calibration and then followed by a second phase in which the impacts of climate change is to be assessed. The following model options are used for all the simulations performed (1) CN method for portioning of precipitation between surface runoff and infiltration, (2) Masking method for channel routing and (3) Penman Monteith method for potential evapotranspiration.

SWAT model runs are performed basically for two sets of rainfall data viz., (1) IMD rainfall and (2) Block rainfall data. IMD runs made use of the data for 4 stations where as block level data made use of 120 stations of rainfall data. Rainfall data for the period 1985–1995 has been used for IMD runs. Block level runs made use of the rainfall for the period 1988–2002. Other data sets viz., Soil, temperature and weather data remains same in both the runs. Flow data sets used for calibration include, Upper Pennar Reservoir—1971–2000, Tadipatri 1974–1998, Pennar Anicut—1983–1991, Somasila Reservoir—1979–1993. It was observed that flow

Table 6.1 Hydrological calibration parameters and calibrated values

Calibration parameter	Symbol	Initial estimate	Calibrated value
Curve no. of moisture cond. II	CN2	Estimated using AVSWAT	+6.6 %
Soil available water capacity	SOL_AWC	0.0	0.04

data is intermittent with long periods of no flow. Hence model calibration has been done for Annual and Monthly Runoff Comparisons for Tadipatri, Annual Runoff Comparison for Somasila and Daily flow comparison for Pennar Anicut. The parameters selected for calibration are shown in Table 6.1. Parameters were allowed to vary during calibration process within acceptable ranges across the basin until acceptable fit between the measured and simulated values are obtained at gauge locations.

SWAT simulated surface runoff for Tadipatri is compared with recorded runoff and it is noticed that the model simulated surface runoff is in good agreement with the observed runoff as depicted in Fig. 6.3.

Average annual rainfall is about 660 mm historically; it increased to 709 mm in A2 scenario and 683 mm in B2 scenario. There is an about 8 % increase in rainfall in A2 and about 4 % increase in rainfall in B2 scenario. It is observed that the runoff in the basin is varied from 4 to 11 %. Evapotranspiration losses are high. It varied from 80 to 95 %. In the climate change scenario, runoff in percentage of rainfall is about 19 % in A2 and 15 % in B2. In the climate change scenario, study estimated that the mean annual flow in the river system would be increased by 8 % in A2 and 4 % in B2. Evapotranspiration losses were decreased by about 10 % in A2 and 12 % in B2. The flows showed high inter-annual variability, which in turn reduce the river flow in dry years significantly, which would have serious effects on irrigation supply. An average rainfall increase of 4–8 % caused a 10–15 % increase in river flows. This may be due to an estimated wet condition in the climate change

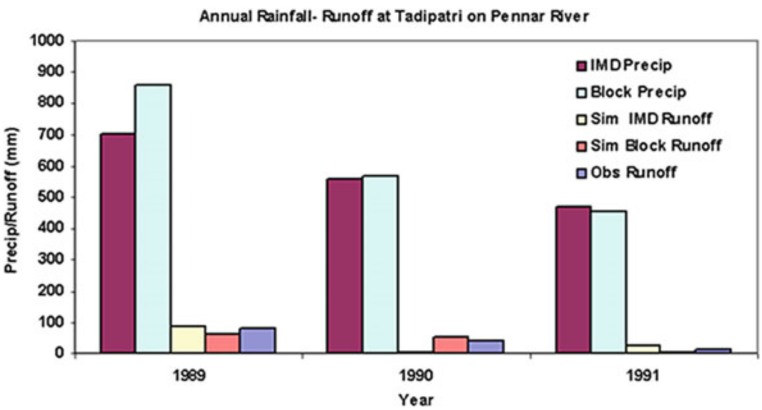

Fig. 6.3 Comparison of annual simulated and observed runoff at Tadipatri

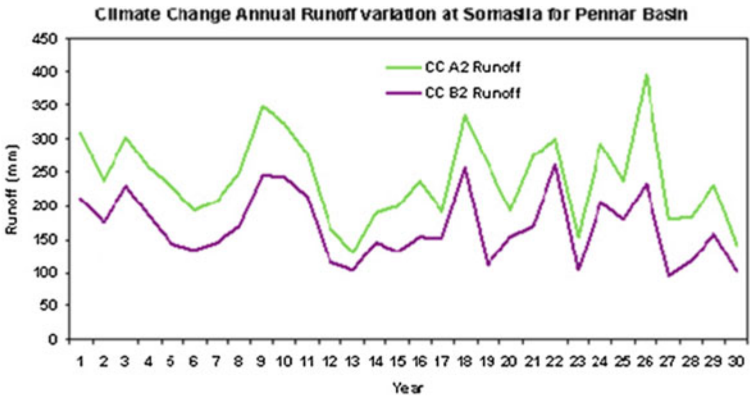

Fig. 6.4 Inter annual variability of runoff in future projected climate change scenarios

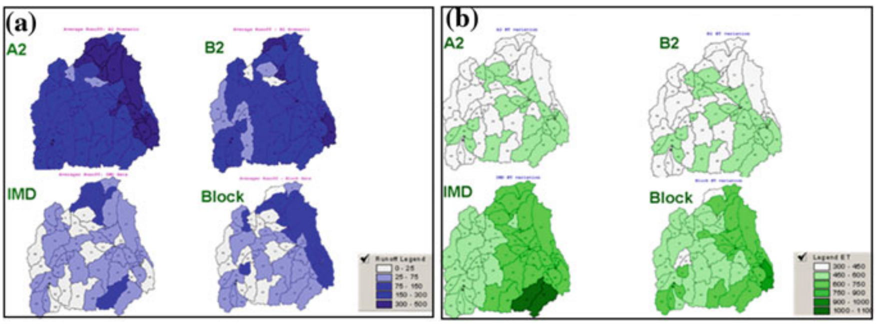

Fig. 6.5 Spatial distribution of **a** average annual runoff and **b** evapotranspiration in climate change scenarios of Pennar river basin

scenario. In A2 scenario, there is about 20 % chance that the rainfall exceeds by 1σ and 4 % exceeds by 2σ. Similarly number of instances in which rainfall is below 1σ is 14 % and 2σ is 4 %. The corresponding numbers in B2 scenario are 18, 6, 14 and 2 % respectively. These values indicate that the extremities in runoff will relatively high in A2 than B2 as shown in Fig. 6.4.

Spatial distribution of runoff and evapotranspiration across the basin in the climate change scenarios are shown in Fig. 6.5. These changes are not uniform across the basin. Increase in runoff is more significant in northern portion of the basin. This is the region, which showed relatively high rainfall and low evapotranspiration over other regions of the basin.

Agricultural Model—EPIC

Agriculture, like rest of India, is the main activity in the Pennar basin. The major food grains grown include rice, groundnut, sorghum, maize and sunflower.

Table 6.2 Crop calendar for Pennar river basin

Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Kharif						Rabi				
South-west monsoon				North-east monsoon		Winter			Summer	
Kharif (rainfed/irrigated rice)						Rabi (irrigated rice)				

Sugarcane, cotton and a variety of other pulses are also grown. These crops are grown either under irrigation or rainfed or both. The area is characterized by two growing season. The major crop growing season is between June and September (*Kharif*). The major source of water for crop production is the rainfall from southwest monsoon during June to September. The second growing season starts in December and last until April (*Rabi*). The main crop grown during *Kharif* season is rice and the source of water is irrigation. It is mostly pumped by electrical driven sub-mersible pumps from the ground source. Table 6.2 shows the relevant cropping calendar.

The four crops rice, groundnut, sunflower, and sorghum are selected for analysis in this study which are already been included in EPIC simulation model, but needed to be modified to reflect local conditions. The model was run for all four crops for *Kharif* season only. Except Rice remaining three crops are rainfed. Rice being an irrigated crop simulation is carried out based on the prevailing conditions in the field. About 47 parameters related to crop phenology, its environment and crop growth in a stressed environment are used in EPIC. Parameter values for the selected crops and the management practices associated with them are based on previous modeling exercises with EPIC and on advice from experts at the Acharya N. G. Ranga Agricultural University (ANGRAU) Hyderabad. EPIC simulated yields are generated at adminstrative blocks falling under four major districts (Kurnool, Chuddapah, Chittor and Ananthpur) of Pennar basin and database developed to describe agricultural practices and environmental conditions in each of these 160 blocks are being used. Soil properties are derived from the National Bureau of Soil Survey and Land use planning (NBSS&LUP) Nagpur paper maps at 1:250 K scale are employed. Validation of crop simulation model EPIC is carried out at districts level. EPIC is forced at block level and yields are aggregated to district level for the years 1989 through 1996 and the annual reported yields for the selected four crops viz., rice, sorghum, groundnut and sunflower. The validation was done using *Kharif* simulated crop yield, which were compared with annual (Kharif + Rabi) reported yields, which were the only data available. The crops, other than rice, are majorly a dryland crop dependent on southwest monsoon, extent of irrigation crops under Rabi season have not been covered in this study. Nevertheless, the validation test is still powerful since a predominance of annual yield is derived from the Kharif season. For instance statistical analysis on crop growing region shows that in the Ananthpur district of Andhra Pradesh the area planted in the Kharif versus rabi season were for rice 2.7 times, and groundnut 41 times. Rice tended to be irrigated in both seasons.

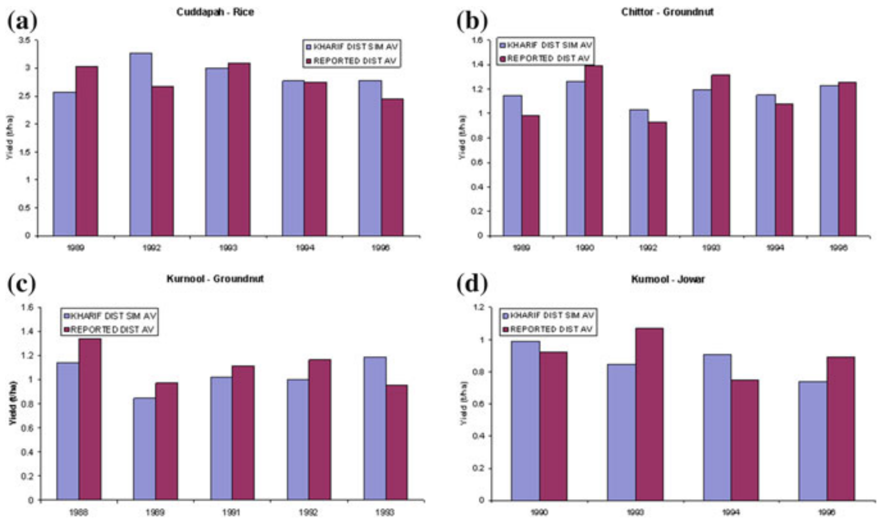

Fig. 6.6 Validation of epic crop simulation model for **a** rice crop at Cuddapah district, **b** groundnut at Chittor district, **c** groundnut at Kurnool district and **d** Sorghum at Kurnool district of Andhra Pradesh

Few examples of closeness between reported and simulated yield can be seen in Fig. 6.6 through 4.7, while performing all these simulations various intermediate checks have been performed, which helped achieve estimated yield close to reported yield.

Addressing the potential impacts of climate change on the four agricultural crops in the Pennar river basin, PRECIS simulated climate change scenarios are downscaled using Delta method. In this study a delta downscaling method is carefully chosen for its proven robust and popular, most likely because it is straightforward and relatively easy to understand. Delta method calculates changes in surface temperatures (ΔT) and relative changes in precipitation (ΔP) and perturb the projected changes to observed climate data and B2 scenarios respectively.

Table 6.3 shows the climate change scenarios for the Pennar region developed by perturbing the projected changes to historical climate data at Block level for both

Table 6.3 Precis projected climate change scenarios for Pennar region

Scenarios	Period	Changes in max temp (°C)			Changes in min temp (°C)			% Changes in RF (mm)		
		Highest	Lowest	Mean	Highest	Lowest	Mean	Highest	Lowest	Mean
A2	Kharif	3.5	3.0	3.1	3.4	3.1	3.2	20.8	−4.5	8.1
B2	Kharif	2.5	2.1	2.3	2.6	2.3	2.4	3.9	−12.0	−5.7
A2	Annual	3.3	2.9	3.1	3.7	3.4	3.6	28.2	9.8	21.3
B2	Annual	2.3	2.0	2.2	2.7	2.5	2.6	7.7	1.0	4.1

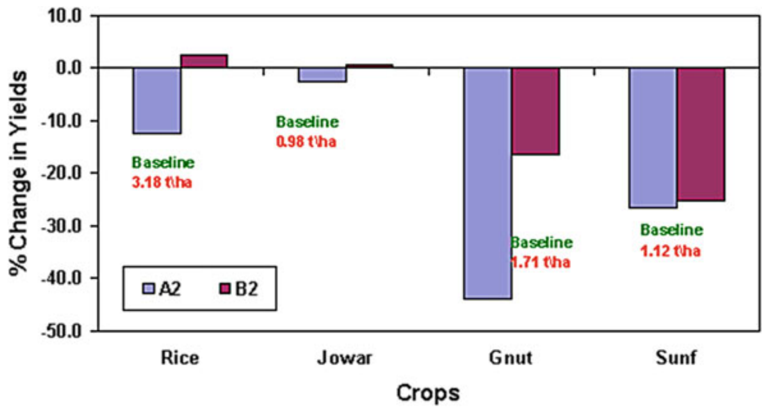

Fig. 6.7 Projected future changes in crop yields over Pennar river basin in a climate change scenario

A2 and B2 scenarios. The A2 scenario shows 21 % increase in the annual mean rainfall in the region and B2 scenario it is about 4 %. Increase in the seasonal mean rainfall for A2 scenario is about 8 % with −5 to 21 % variation, whereas it is −6 % with a range of −12 to 4 % for B2. The region will experience about 3 °C raise in the annual maximum temperature in A2 and 2 °C in B2, respectively. The warming trend will be in the range of 2.9–3.3 °C in A2 and 2.0–2.3 °C in B2. In case of minimum temperature about 3.6 °C raise in A2 and 2.6 °C in B2, respectively. The annual minimum temperature range would be between 3.4 and 3.7 °C in A2 and 2.5 and 2.7 °C in B2.

Under the regional climate change scenarios (both A2 and B2), groundnut showed highest negative deviation, where decrease in the yield appears to be −40 and −19 % for A2 and B2 scenarios respectively.

Following this sunflower showed nearly −18 and −16 % reduction in yield for A2 and B2 scenarios, sorghum varied between −5 and +1 % as shown in Fig. 6.7. Rice seems to have less impact with −11 % reduction decrease in yield under A2 while B2 seemed to have marginal positive impact with +2 % increase in the yield. Change in yield vary within the region due to changes in climate and other key inputs like crop management, soil and topography.

Conclusions

Agriculture represents a core part of the Indian economy and provides food and livelihood activities to a major portion of the Indian population. While the magnitude of the impacts of climate change varies as per region, climate change generally has an impact on agricultural productivity and shifting crop patterns.

Unfortunately, crop agriculture is highly dependent on degrading land quality and most importantly, dwindling and precarious water resource availability. The hydrological features of the region, especially in the Indian sub-Continent, are influenced by monsoons, and to a certain extent, on Himalayan Glacial melt. Under climate change scenario, the spatial-temporal behavior of monsoon will change significantly.

Results revealed that the mean annual flows in the river system would increase by 8 % in A2 and 4 % in B2 whereas increase in evapotranspiration losses were found to be about 10 % in A2 and 12 % in B2. Impact on yields is the combined effect of increase temperature, decreased rainfall and increased CO_2. Three rain-fed crops (Groundnut, Sorghum, Sunflower) show decreased yields under A2, whereas B2 seemed to be relatively better than A2. The decrease is significant for groundnut (−38 % for A2 and −20 % for B2), but compared to groundnut impact were less detrimental for other two rain-fed crops (as shown in graph below). Rice being an irrigated crop shows a decrease in yield by −15 and −7 % for A2 and B2 scenarios respectively. Decrease in yields are mainly due to the further increase in temperature under CC scenarios, as has also been observed in closed and open field experiments.

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