7 Adaptation Strategies to Address the Climate Change Impacts in Three Major River Basins in India

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Abstract

The agriculture sector is highly vulnerable to climate change in many parts of the world. There is an increasing concern among farmers, researchers and policy makers about the potential impacts of climate change on food security and livelihoods. Researchers are using several climate change models to make an assessment of the impacts and identify adaptation strategies. The present chapter reviews the current state of understanding of the climate change impacts on irrigation water in South Asia and specifically on the crop yield and relevant adaptation measures in three major river basins (Godavari, Krishna and Cauvery) in India. Optimization model was used to evaluate the different adaptation practices and their potential to maximize rice production and income, and minimize water use for the mid- and end-century climate-change scenarios. Adaptation practices such as systems of rice intensification, machine transplantation, alternate wetting and drying (AWD) and direct seeding could reduce the water and labour use by 10–15% and stabilize rice production in the long term. The study suggests the need for technology upscaling, which should be backed up with well-planned capacity-building programmes for the farmers.

7.1 Introduction

Climate change is a complex subject that requires an interdisciplinary approach needing an impact assessment to develop corresponding adaptation measures. Therefore, multiple-level assessment and data sets are required to effectively capture the current and future situations. Data on climate, soils, water, crop pattern, crop productivity and socio-economic variables mainly contribute to model estimation. A large and growing body of research shows that socio-economic factors can be as important as the magnitude of a climatic event in determining the impact of environmental change on the agriculture sector (Patt and Gwata, 2002; Fraser *et al*., 2003). However, there are no clear-cut procedures to characterize human coping and adaptation mechanisms as these vary from place to place (Elisabeth *et al*., 2010). Where climate change affects yields, impact models should integrate environmental factors, such as available water and temperature that directly affect yield, with socio-economic factors that encourage pro-active adaptation

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and policy factors that support adaptation. On the other hand, climate change not only affects yield but also its variability (Barnwal and Kotani, 2010). However, little is known about how the available water resources in the future can be effectively used under the changing climate. Therefore, the economics of climate change impacts as well as adaptation to climate change through optimization of the available resources is a challenging area of research.

In this chapter, optimal allocation of resources viz., land, labour and water, to the changing climatic conditions under different irrigation projects of the Godavari, Krishna and Cauvery river basins is discussed. Section 7.2 deals with the background followed by Section 7.3, which comprises the methodology used and a review of understanding the climate change impacts in South Asia. In Section 7.4, the model used for the optimal use of resources is explained along with the study area and projects. Section 7.5 focuses on the results and discussion and finally recommendations. By comparing the results from the individual river basins, the chapter thus draws some lessons for overall management of the water in the river basins.

7.2 Review on Understanding the Climate Change Impacts

South Asia is the home for one-fifth of the world's population and is the most disaster-prone region in the world (UNEP, 2003). Climate change is affecting a large number of people across South Asia in different ways, which includes variability in the monsoons, increase in average temperature, warm winters, increased salinity in coastal areas, reduced discharges from rivers, etc. The Intergovernmental Panel on Climate Change (IPCC) has also projected that the mean annual temperatures of South Asia will increase by 0.5–1.2°C by 2020, 0.88–3.16°C by 2050 and 1.56–5.44°C by the end of the century (IPCC, 2007). High temperatures are likely to reduce the yields of different crops and increase the proliferation of weeds and pests, thus providing new challenges for agricultural scientists (Cruz *et al*., 2007; Nelson *et al*., 2009). In tropical parts of South Asia, temperature rise will negatively impact rice and wheat yields as they are already being grown close to their threshold (Kelkar and Bhadwal, 2007). In sub-humid, semi-arid and arid regions wheat yields are predicted to decline by 6%–9% with a 1°C rise in temperature (Sultana and Ali, 2006). Cash crops such as cotton, mango and sugarcane will be severely impacted with a decadal rise of 0.3°C (MoE, 2003). Thus, the overall impacts of temperatures on agriculture are expected to be negative, threatening global food security.

Droughts or floods are destructive but when they last for longer periods then the effects can be devastating or irreversible (Conway, 2009). Widespread flooding is seen in many small island and delta regions, for example the Mekong Delta. The floods in Myanmar during 2008 devastated 1.75 million ha (Mha) of rice land while in Bangladesh it caused a production loss of about 0.8 t of rice during 2007 (Craufurd *et al*., 2011). In India, 70% of the arable land is prone to drought and 20% to floods and cyclones. Of the total precipitation of around 4000 km^3 in the country, availability of surface water and replenishable groundwater is estimated at 1893 km^3. But due to the variations of topography and uneven distribution of rain over space and time, only about 1123 km^3, including surface water and groundwater resources, can be put to beneficial use (Aggarwal *et al*., 2012).

As a result, water scarcity is expected to become an ever-increasing problem due to the changing climate in India. The water balance will change due to the accelerated rate of evaporation from soil and water bodies and transpiration from plants. Several studies have shown that unless we adapt, there is a probability of a 10–40% loss in crop production in India by the end of the century owing to global warming (Aggarwal, 2009; Knox *et al*., 2011).

Among other things, the river basins are going to be highly affected by sedimentation, reducing water storage, water availability (due to poor monsoon) and area under production. The per capita water resource availability of the basins in India also varies from a low of 240 m^3 (Sabarmati Basin) to a high of 17,000 m^3 (Brahmaputra Basin) (Amarasinghe *et al*., 2005). Authors also reported that many river basins record significantly lower per capita water availability in terms of total renewable water resources, thus increasing the demand for water resources. There are several factors influencing water supply and demand in the basins such as population growth, urbanization and income, changes in dietary preferences, irrigation expansion and environmental flow requirements.

Though there is much concern about reduced water supplies and the substantial impact of climate change in crop production in South Asia, still there is limited understanding of the adaptation strategies needed. Adaptations are adjustments or interventions which take place in order to manage the losses or take advantage of the opportunities presented by a changing climate (IPCC, 2001). Adaptation occurs at two levels: (i) farm-level adaptation, which mainly focuses on farming-related interventions or adjustments and are related to short-term periods and influenced by seasonal climate variations and local agricultural cycles; and (ii) the regional- or national-level adaptation, which focuses on the agricultural production at macro-level linking domestic and international policies (Kandlinkar and Risbey, 2000; Bradshaw *et al*., 2004).

Several adaptation measures have already been examined by researchers. For example, Palanisami *et al*. (2011) have examined the adaptation measures such as systems of rice intensification, machine transplanting, alternate wetting and drying and maize water management options and incorporated them in the optimization model that could help minimize the incidence of climate change impacts on crop yields, labour use and water use. In addition, there are various other adaptation practices, such as direct seeding of rice and drum seeding of rice, which are gaining acceptance among farmers (Gurava Reddy *et al*., 2013). Abraha and Savage (2006) studied the potential impact of climate change on maize yield at Cedara, KwaZulu-Natal, South Africa with different planting dates, such as normal, 15 days earlier and 15 days later. The farm management components appear to be prominent in the literature (Till *et al*., 2010) where most of the adaptation practices included the adjustments in farm management and technology, followed by knowledge management, networks, governance, diversification, government interventions and farm financial management.

7.3 Methodology

7.3.1 Selection of river basins

Godavari, Krishna and Cauvery are some of the major river basins covering central and southern parts of India (Fig. 7.1). The highlights of each river basin are given in Table 7.1. The rainfall pattern ranges from humid to arid and the basins have diversified cropping patterns (rice, cotton, chilli, banana, sesame, maize, groundnut, pulses), indicating water variability over the years due to climate change. The river basins are also more adverse to climate variability in their hydrological regime, which affects irrigation to a large extent. However, there is a need to adapt to new management strategies and practices to overcome water scarcity and achieve food security in the irrigation projects throughout the basins. Results from a study conducted by Gosain and Rao (2012) on impact assessment of water resources from the Godavari Basin show that the water balance, mean annual precipitation, water yield and sedimentation are likely to increase along with temperatures in the mid- and end-centuries compared to the baseline scenario. The simulations of rainfed maize, sorghum and rice yields also indicated the adverse effect due to increases in temperatures, although increased rainfall and change in management practices can partly offset these effects (Kattarkandi *et al*., 2010; Srivastava *et al*., 2010).

7.3.2 Model

Palanisami *et al.* (2011) have estimated production functions focusing on the relation between yield and its variability in the context of climate change. The authors have estimated the Just–Pope production function using the maximum likelihood method by assuming the relation between yield of a crop and climate variables (temperature and

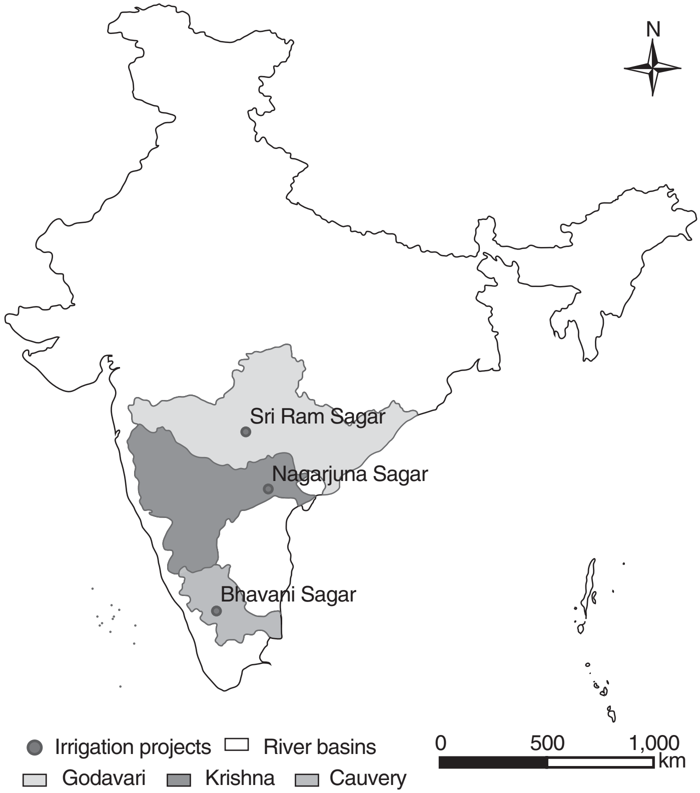

Fig. 7.1. Map showing the projects in the respective basins in India.

Table 7.1. Details of the Godavari, Krishna and Cauvery river basins (from http://www.india-wris.nrsc.gov.in).

Details	Godavari	Krishna	Cauvery
No. of states covered	6	3	3
Catchment area (km^2)	312,812	258,948	81,155
Length (km)	1,465	1,400	800
Annual rainfall (mm)	1000–3000	784	956
Average water resource potential (Mm^3)	110,540	78,120	21,358
Utilizable surface water resource (Mm^3)	76,300	58,000	19,000
No. of hydrological observation stations	17	53	34
No. of flood forecasting stations	77	9	0
Major crops	Rice, wheat, maize, sugarcane, cotton	Rice, cotton, chilli, maize, sugarcane, groundnut, millet and horticultural crops	Rice, sugarcane, maize, groundnut, banana, turmeric, sesame oil, etc.

precipitation) for different districts (Just and Pope, 1978). In the present study, functions developed by the authors were fitted for an irrigation project in Godavari, Krishna and Cauvery river basins. A quadratic form was assumed for the mean function (Isik and Devadoss, 2006; Ranganathan, 2009), which ensures positive output variance. In addition, the riskiness of an input variable was also derived from the sign of the coefficient. The mean function was used to study the maximum and minimum possible yields and also the impact of climate change on the crop yield.

The first and second order conditions were derived by assuming that precipitation and temperature will vary and technology will be held at the current level. None the less, accurate region-specific predictions for changes in temperature and rainfall are needed to capture the impact of climate change. Gosain and Rao (2012) have predicted the season-wise changes in the Godavari River Basin for baseline period (1960–1990), mid-century period (2021–2050) and end-century period (2071–2098).

Two scenarios were formulated based on the mid-century and end-century periods (Table 7.2). The mid-century scenario for kharif[1] season showed an increase of 1.93°C and an overall increase of 13.6% in precipitation. This scenario is denoted by 1.93°C/13.6% and for the rabi[2] season the scenario is 2.22°C/13.6%. Similarly, the end-century scenarios for kharif and rabi are respectively 4.03°C/17.8% and 4.28°C/17.8%. In all these scenarios, only the annual change in precipitation (and not seasonal changes) is considered, as the annual precipitation reflects inter-seasonal water accumulation. These predicted changes were used in the mean and variance functions to predict the average yield and variability in yield induced by climate change.

The precipitation is increasing in both scenarios but the climate models do not have information on the rainfall distribution pattern. There can be a sudden deluge where the present storage reservoirs are not sufficient to meet the demand. The Assessment Report 4 (AR4) by IPCC noted that the frequency of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides and mud flows. At the same time, the number of rainy days has decreased. Analysis of rainfall data for India highlights the increase in the frequency of severe rainstorms over the last 50 years. The number of storms with more than 100 mm rainfall in a day is reported to have increased by 10% per decade (UNEP, 2007). However, due to storage-related issues, the actual irrigation water availability can be decreased in contrast with the projected increased rainfall, which would increase the demand for food grain production.

The projected changes from Table 7.2 were assumed to be same for all the three river basins for modelling purposes as the estimates for Krishna and Cauvery basins are not available.

The parameters were estimated by using the following equation with the assumption that $\omega_{it} \sim N(0,1)$, the likelihood function is given by:

Table 7.2. Projected changes in climatic variables during kharif and rabi seasons (calculations based on figures from Gosain and Rao, 2012).

Change in mean daily average temperature (°C)	Kharif (June to November)	Rabi (December to April)
Change from baseline to mid-century	1.93	2.22
Change from baseline to end-century	4.03	4.28

Change in mean precipitation (%)	Kharif (June to November)	Rabi (December to April)	Overall
Change from baseline to mid-century	12.5	17.6	13.6
Change from baseline to end-century	13.0	53.4	17.8

$$L=\left[\frac{1}{2\pi}\right]^{N/2}\prod_{t=1}^{T}\prod_{i=1}^{R}\left[\frac{1}{h\left(x_{it};\delta\right)}\right]^{1/2} \exp\left[-\left\{y_{it}-f\left(x_{it};\beta\right)\right\}^{2}/2h\left(x_{it};\delta\right)\right] \quad (7.1)$$

where, R is the number of districts and T is the number of time periods and $N=RT$. So the log likelihood function is given by:

$$\ln L=-\frac{1}{2}\left[N\ln(2\pi)+\sum_{t=1}^{T}\sum_{i=1}^{R}\ln\left(h\left(x_{it};\delta\right)\right)+\sum_{t=1}^{T}\sum_{i=1}^{R}\frac{\left\{y_{it}-f\left(x_{it};\beta\right)\right\}^{2}}{h\left(x_{it};\delta\right)}\right] \quad (7.2)$$

This was then maximized to estimate the parameter vectors β and δ. STATA software package has inbuilt *ml* command and it was used to maximize the log likelihood function.

The climate change scenarios and the most likely management options considered in the study are given in Tables 7.3 and 7.4.

The scenario S1 reflects the current state of affairs. Scenario S2 corresponds to 'near future' status. This scenario assumes a 10% likely reduction in water availability for agriculture and a 5% reduction in labour availability. The reduction in water availability is based on the assumption that, in spite of increased and uneven precipitation predicted by climate change scenarios, the share available for agriculture will be reduced due to increased population, domestic consumption demand and industrial use. The Krishna and Cauvery river basins also fall under arid and semi-arid regions (Table 7.1). Similarly, reduced labour supply is due to migration from rural areas and labour demand met by agricultural mechanization. In the mid-century scenario, S3, the productivities of the crops during kharif and rabi seasons are considered. The last scenario, S4, uses the end-century predictions of yield levels. The eight management options are based on promising technologies for rice and maize (Table 7.4).

Table 7.3. Climate scenarios and resource availability considered in the study.

Scenario symbol	Description of the scenario
S1	Current levels of yield, water availability and labour availability
S2	Current level of yield and 10% reduction in water availability and 5% reduction in labour availability, as observed from the past data in the basin (near future)
S3	Projected mid-century yield levels and 10% reduction in water availability and 5% reduction in labour availability
S4	Projected end-century yield levels and 10% reduction in water availability and 5% reduction in labour availability

Table 7.4. Management options considered in the study.

Management option – symbol used	Description of the option
M1	Current management intervention
M2	System of Rice Intensification (SRI) is an improved rice cultivation practice, which could save 20% irrigation water
M3	SRI + Machine Transplanting (MT) will result in a 15% reduction in labour use for rice
M4	Alternate Wetting and Drying (AWD) will result in reduction of water use for rice by 10%
M5	AWD + MT
M6	Maize Water Management (MWM) will result in a 10% reduction in water use for maize
M7	AWD + MT + MWM
M8	SRI + MT + MWM
M9	Direct Seeding of Rice (DSR) will result in a 20% reduction in water use, 10% reduction in labour and 10% reduction in yield

For example, system of rice intensification (SRI) is the most recommended technology for rice cultivation and maize water management (MWM) for maize in the same season. The SRI and machine transplanting as modified SRI (MSRI) with specified spacing, has been implemented in the Krishna and Cauvery river basins of Andhra Pradesh and Tamil Nadu, which resulted in a 10% reduction in water and a 15% reduction in labour (Kakumanu *et al*., 2011; Lakshmanan *et al*., 2012). Similarly, reduction was seen in the alternate wetting and drying, and direct seeding of rice (Gurava Reddy *et al*., 2013). Rice and maize were considered in the same season under the command area for the optimum allocation of resources, based on the historic cropping pattern.

For minimizing water use, four targets for rice production and income were fixed, as given in Table 7.5. The targets are desired for rice production as the basins are known for rice production and hence stabilizing rice production under the climate change scenarios is important.

The target T1 refers to the current situation. The maximum possible rice production and maximum income achievable under eight management options are the targets to be met while optimizing water usage. For the second target, T2, the maximum rice production and income levels possible are derived when available water and labour are reduced by 10% and 5%, respectively. The same target levels are also used in T3 and T4, where the productivity is reduced by climate change.

The details of the optimization framework developed are given in Appendix 7.1. In this optimization framework, the objectives are first prioritized as stated above. First priority is given to maximum rice production as food security is of primary importance for society.

The second priority is given to maximum income, as it will ensure a better livelihood for the farmers. A new constraint is used while running the linear programs to meet the second objective, which will ensure that the rice production will be at least equal to the maximum level as dictated by the first objective. Thus, the results of the first two objectives will ensure maximum food production and a better livelihood.

The third objective is to minimize water usage in agriculture. This objective is important because, as shown by historical data, the share of water use for agriculture is declining over the years as demand increases for other sectors. The results of the first two objectives are incorporated as constraints in meeting the third objective. Thus, the results of all the three optimization models will provide a complete framework to plan for optimum land and water use for the triple targets: increased food production, increased income and reduced water use.

7.3.3 Study area for model application

One project case from each of the three river basins, Godavari, Krishna and Cauvery, were selected for the study, namely the Sri Ram Sagar Project (SRSP) and Nagarjuna Sagar Project (NSP) from Godavari and Krishna river basins, respectively, and the Lower Bhavani Project (12 districts located within the Bhavani Sagar) from the Cauvery Basin (Fig. 7.1). The details of the projects are

Table 7.5. Target levels with minimum water use.

Target	Description
T1	Current maximum rice production and maximum income
T2	Near future[a] maximum rice production and maximum income
T3	Near future maximum rice production and maximum income with mid-century climate change-induced productivities
T4	Near future maximum rice production and maximum income with end-century climate change-induced productivities

[a]Near future represents the next 20 years.

summarized in Table 7.6 and discussed in the following sub-sections.

Sri Ram Sagar Project

The Sri Ram Sagar Project (SRSP) is a multi-purpose project, located across the Godavari River near Pochampad of Nizamabad District in Andhra Pradesh. The project was cleared in 1946 for utilization of 1869 million m^3 (Mm^3) of water from the Godavari River. As a result of an inter-state accord, the allocation was increased from 1869 Mm^3 to more than 5664 Mm^3 (http://www.aponline.gov.in; accessed 4 January 2012), but later limited to 3455 Mm^3 due to capacity constraints. The catchment area upstream of the dam site is 91,751 km^2 and the surface area of the reservoir is 453 km^2. The reservoir water irrigates 0.39 Mha of land through three canals (Kakatiya and Laxmi on the right bank and Saraswathi on the left bank), and supplies nearby areas with drinking water and water for hydropower generation. The water used for hydropower production is later released for irrigation in the Kakatiya Canal, 146 km long, from the SRS Dam. The Kakatiya Canal crosses the Manair River and water is also stored at the Lower Manair Dam. A flood flow canal discharges excess water towards the right bank also flowing into the Lower Manair Dam when the reservoir level exceeds 326 m. In addition, water from the groundwater is also an important source supplementing irrigation in this region.

In addition to irrigation and hydropower, SRSP also provides drinking water to urban and rural areas along the canal system, particularly to the towns of Karimnagar and Warangal located in Andhra Pradesh. The drinking water allocation for rural areas ranges from 55–100 l per capita day^{-1} (l cap^{-1} day^{-1}), whereas for urban areas it is 70–120 l cap^{-1} day^{-1}. The population served by SRSP is approximately 12.6 million.

The cropping pattern proposed for SRSP in the early stages was to grow only irrigated dry crops such as maize, groundnut, sorghum and pulses. However, the cropping pattern has changed over the years into more water-demanding crops, and rice, together with maize and groundnut, are now the main crops (SRSP, 2009) in both kharif and rabi seasons, which poses a major challenge for water distribution and management. The cropping pattern changes with the variation in rainfall. The mean annual rainfall in the area of SRSP is 900 mm of which more than 75% is received in the south-west monsoon period (kharif season). In the last decade, the driest year was

Table 7.6. Highlights of the three irrigation projects considered in the study.

	Sri Ram Sagar	Nagarjuna Sagar	Lower Bhavani
Name of the basin	Godavari	Krishna	Cauvery
No. of districts covered	4	5	12
Catchment area (km^2)	91,751	215,185	4,200
Project type	Multi-purpose	Multi-purpose	Multi-purpose
Project capacity (TMC)[a]	112	408	70
Length (km)	364.5	382	200
Command area (ha)	387,456	896,000	84,000
Annual rainfall (mm)	878	785	730
On-farm application efficiency – wet crops (%)	34.5	33.10	38
Average on-farm application efficiency (%)	57.28	38.93	48
Overall project efficiency (%)	44.66	21.8	52
Soil type	Black clay to red soils	Black clay to red coarse soils	Red loamy soils
Major crops	Rice, maize and groundnut	Rice, cotton, chilli, maize, groundnut and pulses	Rice, maize, sesame, turmeric, sorghum and pulses

[a]TMC = Thousand million cubic feet.

recorded during 2004/2005, where only 55% of the mean annual rainfall was received and no water was available through canals to the command area downstream (SRSP, 2009). Hence there is a need for optimization of resource use by maximizing the food production and income with minimum water use through improved water management practices.

Nagarjuna Sagar Project

The Nagarjuna Sagar Project (NSP) is one of the largest and highest masonry dams (125 m) in the world. It is situated downstream of the Srisailam Reservoir on the main Krishna River in Andhra Pradesh. It is a multi-purpose project with irrigation, hydropower and flood-control components.

The catchment area of the dam is 215,193 km^2; the annual rainfall in the catchments is 889 mm, the maximum observed flood is 30,050 m^3 s^{-1} (cumec) and the design flood (return period 1000 years) is 58,340 cumec. NSP complex has a substantial capacity for hydropower generation. It has one conventional and seven reversible units, each with 110 MW capacity. The right bank canal powerhouse has three units of 30 MW each and the left canal powerhouse has two units of 20 MW each.

NSP annually provides 7465 Mm^3 water on average to a command of 0.89 Mha. The project was completed in 1974 and comprises a dam with two canals taking off on either side. The Nagarjuna Sagar Right Canal (NSRC) is 203 km long and creates an irrigation potential for 0.47 Mha in Guntur and Praksam districts, while the Nagarjuna Sagar Left Canal (NSLC) is 179 km and creates irrigation potential for 0.42 Mha in Nalgonda, Khammam and Krishna districts. Of the five districts under NSRC and NSLC, Guntur District has the highest command area of 284,000 ha covering 39 *mandals* (blocks) in the district.

The command area under NSP is designed for a mixed cropping pattern, that is, one-third wet and two-thirds irrigated dry (ID). The areas close to the head reaches were localized as ID rabi (December to April) and the command in the lower reaches were localized as kharif wet (June–November). Water is supplied for a single crop, either only for kharif wet or rabi ID. Rice is the major crop grown in the kharif season and ID crops are sown after October in rabi. The important ID crops grown in the project area are chilli, cotton, pulses and groundnut. The cropping pattern observed from 1995/1996 to 2004/2005 has not had much variation (I&CAD, 2009). Whatever changes that have occurred in the cropping pattern are due to the availability of water in the reservoir, coupled with the seasonal rainfall pattern. Most of the cropping takes place during the kharif season. Though the upper reaches are designed for ID crops, wet crops are generally sown, resulting in excess use of water compared to its original design, depriving tail-end users. The tail-end users are thus compelled to cultivate ID crops or supplement irrigation of wet crops with groundwater. The water in the canal flows continuously in kharif and on and off during the rabi season. The crops grown also depend on the soils, climatic conditions, irrigation facilities, and market and price conditions. Rice is the most favoured crop for the farmers as it is a staple food. In the rabi season, farmers cultivate pulses or vegetables and ID crops such as groundnut and maize.

In NSP, problems regarding availability of water at the tail-end exist due to excess use of water at the head regions. The average on-farm efficiency is 39% and the project efficiency is 21.8% (I&CAD, 2009). The roles and responsibilities of the water user associations are not clearly known and defined. Water management options are also poorly disseminated to the farming community. Hence, there is a need to address some of these challenges by adapting to water management practices to improve water use efficiency at the farm and project level.

Lower Bhavani Project

The Lower Bhavani Project (LBP) is the major project in the Cauvery River Basin (CRB), which lies in the eastern part of Tamil Nadu. CRB covers 12 districts of Tamil Nadu.

The Erode District makes up about 16% followed by Coimbatore with 14% of the total basin area (Government of Tamil Nadu, 2006). The region experiences rainfall during both the summer south-west (June through September) and early winter north-east monsoons (October through December), with the peak rainfall during the north-east monsoonal season. While most parts of central and northern India experience decreasing rainfall in both seasons, the peninsular parts of India, particularly the region 9–16°N encompassing the CRB, shows a tendency for increasing rainfall. This increase is particularly strong during the north-east monsoonal season. While part of this trend may be due to multi-decadal monsoonal variability, a potential impact of anthropogenic greenhouse gas (GHG) forcing cannot be ruled out (Annamalai and Nagothu, 2009). The forced emerging signal due to increase in GHG concentrations, or climate change, is manifested as a long-term trend. At any rate, the observed long-term changes in rainfall may have already been influencing the agriculture sector in the CRB.

The total cropped area of the CRB, Tamil Nadu is about 1.8 Mha. Rice is the major food crop in all the districts and is predominantly grown in Thanjavur, Thiruvarur and Nagapattinam, with 66.78% of the total rice production in the basin. Sorghum and pulses make up the second and third most important crops in the basin, with 16.25% and 15.13% shares, respectively.

The project is facing water shortages due to reduced inflows over years and increasing withdrawal for the domestic sector. Groundwater use is increasing to offset the reduction in canal supplies. Water usage for agriculture is also high with poor water use efficiency, especially in the case of the rice crop. Improving the water use efficiency at system level will help to address the water shortages that will increase in the future.

7.4 Results and Discussion

As water use in these projects is mostly during the kharif crop season (June–November months), optimization of the resources was carried out for kharif season for all three river basins. The mean functions, variance functions, standard errors of the coefficients and log-likelihood function of all the three projects for different crops are presented in Appendix 7.2. The maximum and minimum possible yields and also the impact of climate change on the crop yield for all the three projects are presented in Appendix 7.3. The project-wise optimization results are presented below. The results have highlighted only the significant different management options.

7.4.1 Godavari river basin – Sri Ram Sagar Project

Current rice production in the kharif season is 570,000 t, with a predicted production of 500,000 t in each of the next 20 years. The corresponding predictions for the mid- and end-century are 480,000 t and 360,000 t, respectively (Fig. 7.2). Adoption of SRI in the current and future scenarios increases the yield by 13%, AWD by 11%, and combination of SRI–machine transplantation with MWM by 23%.

Total gross income from crop production during the kharif season using the current market price of the crops is at present Rs2.9 bn and will reduce to Rs2.67 bn over the next 20 years assuming that the same prices would prevail. At mid- and end-century, the gross income will reduce to Rs2.52 and Rs2.37 bn, respectively (Fig. 7.3).

In order to maintain the current level of production and gross income 3868 Mm^3 of water is required, and this will decrease to 3479 Mm^3 in the near future. However, during the mid- and end-century, the water required for maintaining the current level of production and gross income will be 3679 and 4794 Mm^3, respectively (Fig. 7.4). This can be reduced by adapting management practices like SRI with machine transplantation, MWM and AWD. The water use with the adaptation of SRI and AWD reduces by 17% and 9.5%, respectively. A similar trend was noticed for the near future, and mid- and end-centuries.

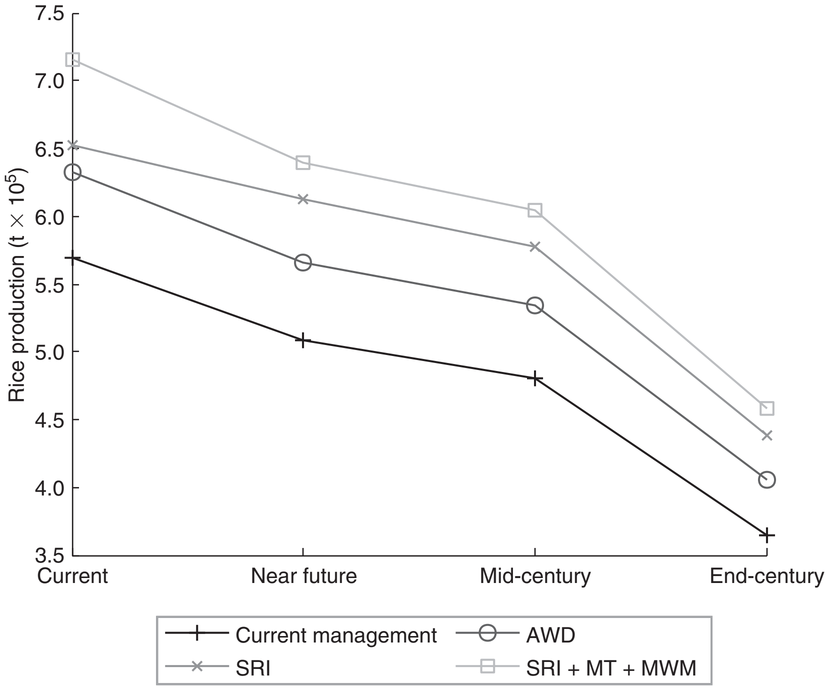

Fig. 7.2. Rice production under different scenarios and management options in the kharif season.

7.4.2 Krishna basin – Nagarjuna Sagar Project

Current rice production in the kharif season from NSP is 380,000 t and will be about 300,000 t, each season, in the near future (next 20 years) and mid-century. The production will be 250,000 t at the end of the century (Fig. 7.5). Adding water-saving technologies such as SRI and AWD will increase rice production by about 50,000 to 100,000 t, which is about 13–26% of current production. With the addition of machinery transplantation (MT) along with the SRI and AWD options, the production levels remain the same but the labour use increases for each option. MT is addressing the issue of labour scarcity both in present and future time periods. Direct seeding of rice (DSR) is also showing better yields compared to the current practices by improving water productivity, except in the near-future scenario. DSR reduces water use without any variation in the production levels. The system is presently practised at the tail-ends of the canal systems. This practice is expected to be increasingly adapted during the water stress years at mid- and end-century periods.

The second objective is to maximize income from crop production during the kharif season. Total gross income from crop production during the kharif season with the current level of production is Rs15.7 bn and will reduce to Rs15.4 bn in the next 20 years. During the mid- and end-century, the gross income will reduce to Rs12.7 and Rs11.8 bn, respectively (Fig. 7.6). The SRI and AWD options improve the gross income by Rs0.42 and Rs0.18 bn with the current practices. MT does not influence the production levels and income levels with the SRI and AWD options for the near future and for the mid- and end-century periods, but will reduce the scarcity of labour and minimize water use.

In order to maintain the current level of production and gross income, 8384 Mm^3 of water are required. The water requirement decreases with change in technologies. SRI

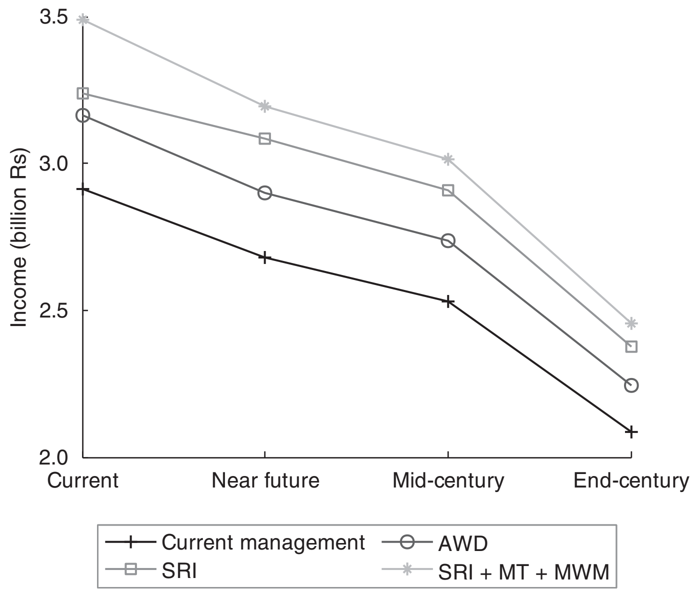

Fig. 7.3. Income under different scenarios and management options during the kharif season.

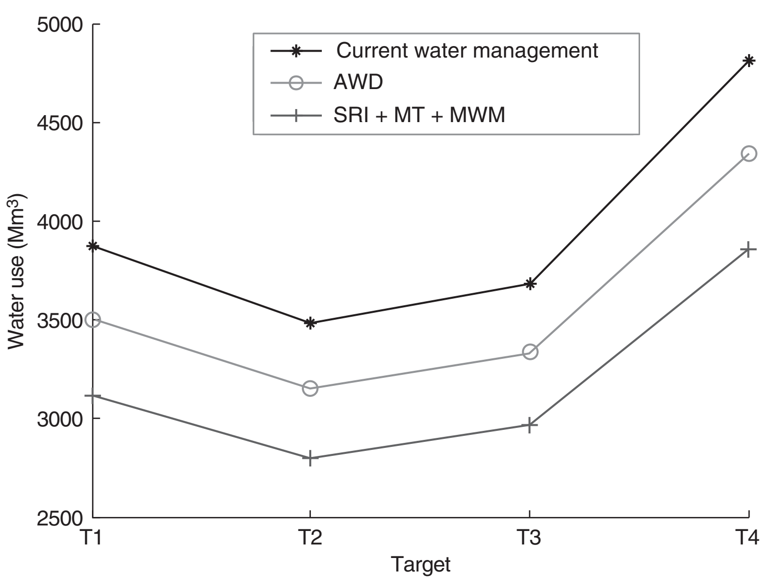

Fig. 7.4. Water use under different scenarios and management options, kharif season.

requires 7067 Mm^3 (15.7% less), AWD requires 7726 Mm^3 (7.8% less) and DSR requires 8149 Mm^3 (2.8% less). The minimum water requirement to maintain the current level of production and gross income is more or less similar during the near future, and mid- and end-century periods.

It is therefore important to see how production and income can be maintained in the future using various adaptation strategies. As indicated earlier, water- and labour-saving technologies will help to minimize the production and income losses due to climate change impacts, and will also reduce water

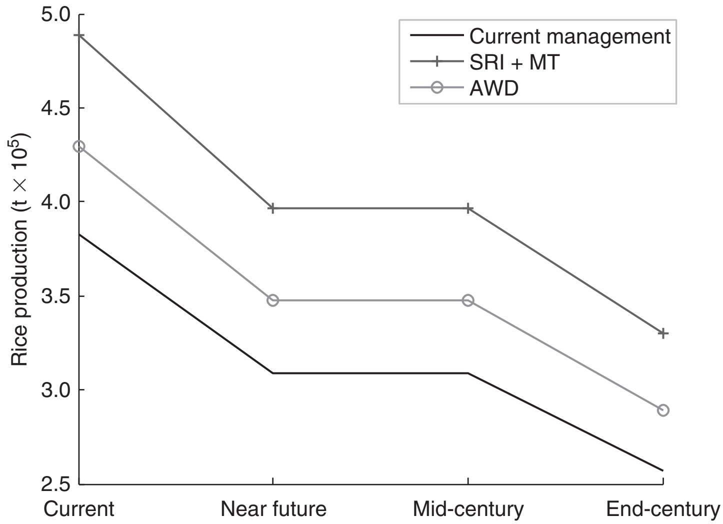

Fig. 7.5. Rice production under different scenarios and management options during the kharif season.

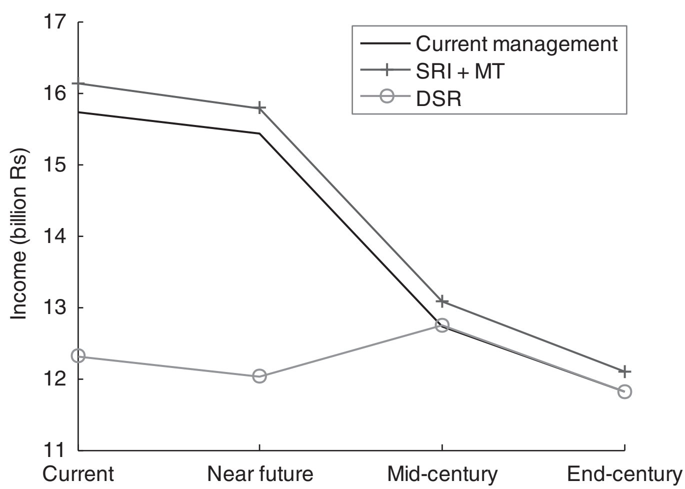

Fig. 7.6. Income for different scenarios and management options – kharif season.

use. From the optimization results it was observed that when the water- and labour-saving technologies are adopted in crop cultivation, the current rice production will be 710,100 t (24.5% increase), 640,000 t (12.2% increase) in the next 20 years, 600,000 t (5.2% increase) at mid-century and 460,000 t at end-century (19% decrease), respectively. This end-century result of 19% reduction in rice production can be compared to 37% reduction if no technological interventions are made. Water management and labour-saving technologies will help to address the negative impact of climate change in rice production in the project area. A similar trend is seen in the case of gross income and water use during different periods.

7.4.3 Cauvery river basin – Lower Bhavani Project

Current rice production in the kharif season is 118,000 t and is predicted to be 105,000 t each season in the next 20 years (near future). SRI with machine transplantation and maize water management has increased the yield by 17%, SRI 14% and AWD 11%. As per the mid-century predictions, the production will be 91,000 t (a decrease of 22.9%) and it will be 80,000 t (a decrease of 32.2%) at the end of the century (Fig. 7.7).

The major crops from which farmers derive income during the kharif season are rice and maize. At present, the total gross income from crop production during kharif is Rs709.8 million and is predicted to reduce to Rs633.7 million, every season, in the next 20 years. At mid- and end-century, the gross income is predicted to reduce to Rs541.7 million (23% reduction) and to Rs474.0 million (33% reduction), respectively (Fig. 7.8). But with the adoption of SRI, MT, AWD and MWM practices the income can also be increased by 11%–17%.

In order to maintain the current level of rice production of 118,000 t and gross income of Rs709.8 million during the kharif season, the amount of water required is 480 Mm^3. However, if SRI techniques are used for rice and MWM is used for maize, the same targets can be achieved with 394 Mm^3 of water, saving 86 Mm^3. In the near future, the total water available will be 432 Mm^3. With this amount of water, and the current water management options, the maximum achievable rice production is 105,000 t and maximum income will be Rs633.7 million. Application of SRI to rice crop will decrease the need for water by 86 Mm^3, improving water productivity with the decrease in water consumption by 9%–18% in all the scenarios except in the end-century.

However, at mid- and end-century, due to the negative impacts of climate change on crop productivities, there will be a greater water demand to maintain the current level of productivity and income (target T1) or at least near-future productivity and income (T2). To achieve this, we set the targets T3 and T4 listed in Table 7.5. These targets are not possible to be met with the current availability of water and current management interventions. Table 7.7 provides the predicted quantity of water needed to attain the targets under various management options.

It is evident from the Table 7.7 that SRI is a very promising management option to minimize water use. The excess demand for water during mid-century can be nullified by applying this technique. However, at the end of the century, the effect of climate change will be much more severe, and more water will be needed to maintain target T2. Even with SRI intervention there will be a 24.6 Mm^3 deficiency of water.

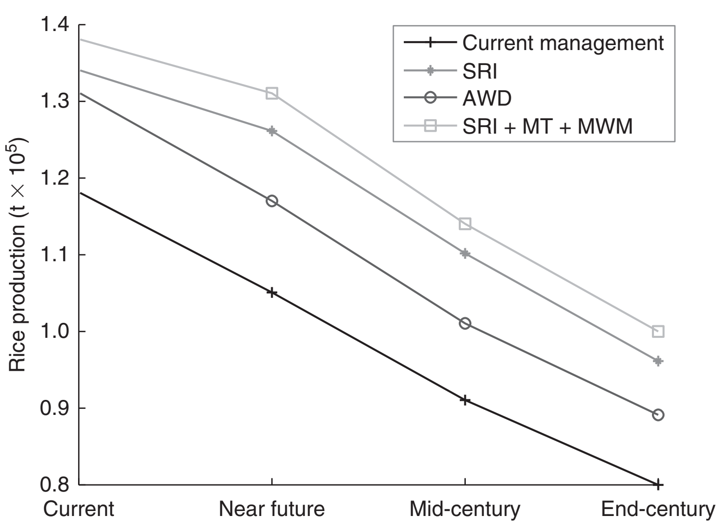

Fig. 7.7. Rice production for different scenarios and management options during the kharif season.

Adoption of water- and labour-saving technologies contribute to rice production in the project area. In all the cases, SRI resulted in higher production, gross income and water saving, compared to MT and AWD. MT helped the rice production by releasing labour to cultivate additional rice areas. In the future, labour scarcity is expected to lead to a reduction of areas under rice cultivation, as it will be a constraint to the transplanting operations. MT helps to ease the labour scarcity by 20–25%. It is clear that the returns from investing in water management technologies for coping with future climate change impacts are high, if the farmers adopt them properly (Palanisami *et al*., 2011).

7.5 Conclusions and Recommendations

Climate change impacts will, in the long run, reduce rice production in the project areas by 25–30%. Water is the key long-term constraint in rice production and land currently under fallow due to water scarcity will be a key issue to address in the future. By implementing various water- and labour-saving technologies (MT, SRI, DSR and AWD), one can minimize the reduction in rice production by 20–25% during the mid- and end-century periods, and these technologies will also help to minimize water use as well.

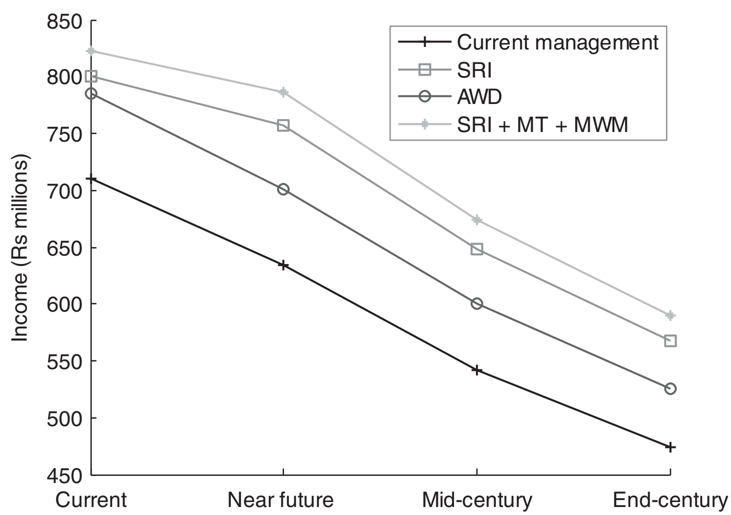

Fig. 7.8. Income under different scenarios and management options during the kharif season.

Table 7.7. Water use for different scenarios and management options during the kharif season.

Management option	Target			
Rice production (t)	118,000	105,000	105,000	105,000
Income (Rs million)	709.8	633.7	633.7	633.7
Water available (Mm^3)	480	432	432 and mid-century projected crop productivities	432 and end-century projected crop productivities
Water required (Mm^3)				
Current management	480.0 (0.0)	432.0 (0.0)	493.1 (–61.1)	557.0 (–125.0)
SRI	394.2 (+85.8)	355.8 (+76.2)	405.3 (+26.7)	456.6 (–24.6)
AWD	437.1 (+42.9)	393.9 (+38.1)	449.2 (–17.2)	506.8 (–74.8)
SRI + MT + MWM	393.7 (+86.3)	355.3 (+76.7)	377.9 (+54.1)	450.6 (+18.6)

+, excess water availability; –, deficit.

The results from the three basins have shown that adoption of various water management technologies improves the water productivity and income from the projects. However, the performance of the technologies varied across the basins, indicating their mixed performance. The factors contributing for the successful adoption have to be studied and follow-up actions can be initiated in other basins.

However, in general, the level of technology adoption is currently poor in all the basins due to poor access to the technologies, lack of skills in handling the improved technologies and the recurring costs (Palanisami *et al*., 2014). A recent study conducted in these basins also indicated that upscaling the technologies will help address the climate change impacts and hence promotion of the water management technologies is the key intervention to be targeted at basin level (Nagothu *et al*., 2012). These technologies need to be disseminated and up-scaled with a capacity-building framework considering their impacts on the production, income and conservation of water resources. As piloting the technologies on individual farms will not have a major impact, a cluster approach (covering a group of villages in a location for each technology) will be more useful in up-scaling these management technologies.

Notes

1 Kharif is the wet season, which covers the months June/July–November.

2 Rabi is the dry season, which covers the months December–March/April.

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Appendix 7.1. Details of the Optimization Framework

Optimization is done by formulating suitable linear/quadratic programming problems. The objective functions generally included are:

1. Maximize rice production.
2. Maximize farmers' income.
3. Minimize water use in agriculture.

Depending on the project objectives, other goals can also be included, such as maximizing food grain production and minimizing agricultural area.

A set of constraints for various resources like land, water, labour, etc., can be formulated depending on the availability of data for each basin. For example, in the selected basins, the following constraint formulations were made.

Variable	Explanation
x_{sdC}	Area under crop *C* in district *d* during season *s* *C*=Rice (R), Maize (M), Groundnut (G), Cotton (C), . . . *d*=districts *s*=Kharif, Rabi
y_{sdC}	Yield under crop *C* in district *d* during season *s*
A_{sC}	Area under crop *C* in season *s* in all the four districts
P_{sC}	Production of crop *C* in season *s* in all the four districts
AC_s	Total area under cereals in all the four districts in season *s*
w_{sdC}	Water required per hectare for crop *C* in season *s* in district *d*
R_{sdC}	Revenue under crop *C* in district *d* during season *s*

Objective 1: Maximize rice production in kharif

The predominant crops during the season in project areas are, e.g. rice, maize, cotton, chilli, etc.

Maximize rice production: $\sum_{d=1}^{4} x_{sdR} y_{sdR}, s=Kharif$

Constraints:

1. Total area under the crops during kharif season should not exceed the available crop area in the command in the districts (let us say, $d=4$)

$$\sum_{d=1}^{4} x_{sdR} + \sum_{d=1}^{4} x_{sdM} \leq AC_s, s=Kharif$$

2. Total water required for all crops during kharif in all the districts in the project area is less than or equal to the total water available

$$\sum_{c} \sum_{d=1}^{4} w_{sdC} x_{sdC} \leq W_s, s=Kharif$$

3. Total labour required for all crops during kharif in all the districts in the project area is less than or equal to the total labour available.

$$\sum_{c}\sum_{d=1}^{4} l_{sdC}x_{sdC} \leq L_s, s = Kharif$$

4. The normal (average of the last 5 years area) area under rice cultivation during the kharif season in the four districts is approximately in the ratio 1:2.5:1.7:2.5. It is assumed that this area ratio will continue. Hence:

$$x_{sAR} : x_{sKR} : x_{sNR} : x_{sWR} = 1:2.5:1.7:2.5$$

The equivalent linear constraints that are included in the model are:

$$2.5x_{sAR} - x_{sKR} = 0$$
$$1.7x_{sAR} - x_{sNR} = 0$$
$$2.5x_{sAR} - x_{sWR} = 0$$

5. The normal (average of the last 5 years area) area under maize (example) during the kharif season in the four districts is approximately in the ratio 1:5.1:2.6:2.4. It is assumed that this ratio of areas will continue. Hence

$$x_{sAM} : x_{sKM} : x_{sNM} : x_{sWM} = 1:5.1:2.6:2.4$$

The equivalent linear constraints which are included in the model are

$$5.1x_{sAM} - x_{sKM} = 0$$
$$2.6x_{sAM} - x_{sNM} = 0$$
$$2.4x_{sAM} - x_{sWM} = 0$$

6. The normal area under maize is about 70,000 ha. It is assumed that at least this much area should be allotted to the maize crop.

$$\sum_{d=1}^{4} x_{sdM} \geq 70000$$

Objective 2: Maximize farmers' net income

The objective is to maximize farmers' net income during the kharif season. That is:

$$\text{Maximize net income } \sum_{d=1}^{4}\sum_{C} R_{sdC}y_{sdC}, s = Kharif$$

In addition to the constraints described in Objective 1, an additional constraint is included which guarantees that the rice production during the kharif season will not be lower than the maximum level.

That is, if $R_{\max Kharif}$ is the maximum rice production, then the new constraint added is:

$$\sum_{d=1}^{4} x_{sdR}y_{sdR} \geq R_{\max\ Kharif}$$

Objective 3: Minimize water use

The objective is to minimize water use in agriculture. That is:

$$\text{Minimize water use } \sum_{d=1}^{4}\sum_{C} w_{sdC}y_{sdC}, s = Kharif$$

The constraints on water availability and labour are removed and all other constraints that were included for maximizing income are retained. Two new constraints, one for fixing target for rice production and the other one for fixing target for income, are added. If T and MI are maximum rice production and maximum income, respectively, the constraints can be written as:

$$\sum_{d=1}^{4} x_{sdR} y_{sdR} \geq T$$

$$\sum_{d=1}^{4} \sum_{C} R_{sdC} y_{sdC} \geq MI$$

Thus the model will estimate the required minimum quantity of water that will ensure the target rice production T and maximum income MI.

Appendix 7.2. Just–Pope Production Function for the Crops Grown in all Three Projects: Parameter Estimates

	Sri Ram Sagar Project (Godavari)			Lower Bhavani (Cauvery)	
Mean yield	Rice	Maize	Groundnut	Rice	Maize
Precipitation (*R*) (mm)	7.210**	1.458***	–0.140	–0.2329	17.9885***
Temperature (*T*) (°C)	2,245.915**	–1,684.180**	4,621.546**	–190.385***	–15,954.3100***
Trend (year)	42.436***	73.988***	20.096***	42.0260***	2.3598
R^2	–0.001***	–0.001	0.000	0.0003	0.0001
T^2	–40.172	29.238***	–86.010***	0.7508	291.7981***
$R \times T$	–0.151	–0.005	–0.002	–0.0400*	–0.6436***
Adilabad/Nalgonda	–710.666	–443.900***	–237.896***	–	–
Karimnagar/Khammmam	119.036**	317.455***	–40.902	–	–
Nizamabad/Krishna	5.293	168.429	78.230	–	–
Guntur	–	–	–	–	–
Constant	–31,671.7	24,377.59	–61,385.95	7,933.15	219,145.80
Variability in yield					
Precipitation (*R*)	–0.001**	–0.001	0.000	0.0073**	0.0009
Temperature (*T*)	0.629**	0.133*	0.281**	2.8463**	–3.1340***
Trend	0.026**	0.035**	0.029	–0.0522	–0.2699***
Adilabad/Nalgonda	1.074**	0.443	0.656	–	–
Karimnagar/Khammam	0.854**	–0.136	0.347	–	–
Nizamabad/Krishna	1.922***	0.368	1.576	–	–
Guntur	–	–	–	–	–
Constant	–6.100	8.376	2.566	–75.6846	103.1627
Likelihood function	–1,096.8	–1,182.2	–1,081.3	–280.5	–292.1

	Nagarjuna Sagar Project (Krishna)			
Mean yield	Rice	Chilli	Cotton	Groundnut
Precipitation (*R*) (mm)	7.131	1.267	–0.316	–11.764
Temperature (*T*) (°C)	517.565***	–4,550.519***	1,642.900**	2,685.464**
Trend (year)	38.678***	77.024***	7.1934***	25.137***
R^2	–0.001***	0.0002	0.006**	–0.0001
T^2	–9.407***	80.033***	–30.086	–53.971***
$R \times T$	–0.167	–0.065	0.0154	0.425
Adilabad/Nalgonda	–138.399	183.360	–161.045***	–284.919**
Karimnagar/Khammmam	–563.750***	958.678***	–99.833**	–74.356
Nizamabad/Krishna	–155.250	925.118***	–9.513	–16.537
Guntur	206.042***	1,607.058***	107.545***	83.639
Constant	–6,141.211	65,400.22	–22,254.53	–31,988.28
Variability in yield				
Precipitation (*R*)	–0.002**	–0.002***	0.0016***	–0.0009
Temperature (*T*)	0.421	–0.763	0.952***	0.153
Trend	0.022**	0.034*	–0.053**	0.127
Adilabad/Nalgonda	0.030	0.397	–0.793	–0.646
Karimnagar/Khammam	0.289	0.452	–1.080**	–2.490***
Nizamabad/Krishna	0.768*	0.474	–0.433	–1.399**
Guntur	–0.055	1.228***	0.253	–1.252***
Constant	0.501	35.116	–17.845	6.491
Likelihood function	–10,593	–1,167.2	–907.2	–1,026.3

*, Significant at 10% level; **, significant at 5% level; ***, significant at 1% level.

Appendix 7.3. Impact of Climate Change for the Crops Grown in all Three Projects

		SRSP (Godavari)			LBP (Cauvery)	
CC-Scenario		Rice	Maize	Groundnut	Rice	Maize
	Normal yield (kg ha^{-1})	2972	3922	1556	3994	3840
Mid-century (MC) 1.93°C/13.6%	MC-predicted yield (kg ha^{-1})	2747	3708	1254	3469	2182
	Loss (%)	7.6	5.5	19.4	13.2	43
	Standard deviation	575	696	383	225	587
End-century (EC) 4.03°C/17.8%	EC-predicted yield (kg ha^{-1})	2065	3778	338	3033	1990
	Loss (%)	30.5	3.7	78.3	24.1	48
	Standard deviation	1086	789	507	987	684

		NSP (Krishna)			
CC-Scenario		Rice	Chilli	Cotton	Groundnut
	Normal yield (kg ha^{-1})	2944	3568	442	1831
Mid-century (MC) 1.93°C/13.6%	MC-predicted yield (kg ha^{-1})	2923	2947	332	1483
	Loss (%)	0.7	17.4	25.1	19.1
	Standard deviation	452	335	183	647
End-century (EC) 4.03°C/17.8%	EC-predicted yield (kg ha^{-1})	2439	2867	220	913
	Loss (%)	17.1	19.7	50.3	50.2
	Standard deviation	680	145	198	749