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Assessment of Vulnerability and Impact of Climate Change on Crop Production in Krishna river basin of Andhra Pradesh

Praveen Kumar, N. S., *Paul, K. S. R., Krishna Reddy, K., Rao, D. V. S. and Chandra sekhar Reddy, M.

Department of Agricultural Economics, Agricultural College Bapatla Guntur, Andhra Pradesh, India

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Climate change is essentially a long term phenomenon and is supposed to be gradual in its impact for most part. Integrated assessment combining insights of many disciplines is used as a primary tool in order to follow the causal chain of events from perturbations in the environment to the final outcomes. This can be done by first assessing the vulnerability of different regions to climatic change and then quantifying its impact on agriculture using the long term data. The present paper applies a statistical methodology to rank the districts of Krishna river basin in terms of vulnerability and to classify them into different levels of vulnerability by constructing composite vulnerability indices. Also the paper presents the impacts of climatic change on productivity and area under three major crops of Andhra Pradesh by employing Ricardian model. Existing base level area and yields are obtained by substituting average values of the explanatory variables for each district in the area and yield regressions

Key words: Climate Change; Vulnerability Index; Ricardian analysis; Crop production; Krishna river basin; Andhra Pradesh.

INTRODUCTION

Climate Change (CC) or global warming is an important issue on which research is being carried out globally now. CC will have multi-dimensional effect on humanity in terms of several socio-economic parameters. Any scientific study on CC should take into account vulnerabilities of the different regions and then it has to study its impacts on several sectors. IPCC (2007) defines vulnerability as '*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*'. The purpose of the present paper is two-fold. First an attempt has been made to apply a statistical methodology for assessing vulnerability of Krishna river basin of Andhra Pradesh. Among the different sectors, agriculture is the most important sector which will be clearly affected by CC. Hence, the second objective is to study the impact of CC on agriculture in Krishna river basin of Andhra Pradesh using an econometric model.

MATERIALS AND METHODS

Vulnerability Index: Vulnerability to Climate Change (CC) is a comprehensive multidimensional concept affected by large number of related indicators and hence it is necessary to measure the quantum of vulnerability by constructing a vulnerability index for each district. This index is a composite one constructed on the basis of several factors, which are prone to be affected by climatic change. Following Patnaik and Narayanan (2005), these factors can be grouped into five components namely, 1.Demographic 2. Climatic 3. Agriculture 4. Occupational and 5. Geographic. Each one of these components can have several sub-indicators. Using the methodology developed by Iyengar and Sudharshan (1982), a composite index from multivariate data was worked out and based on the index, all the districts falling within the river basin were ranked in terms of their vulnerability to climate change into five different categories namely, less vulnerable, moderately vulnerable, vulnerable, highly vulnerable and very highly vulnerable. There are 10 districts within the river basin namely, Anatapur, Kurnool, Prakasam, Guntur, Krishna, Khammam, Nalgonda, Warangal, Mahboobnagar and Rangareddy. But due to lack of time series data for Prakasm district it was not included in the analysis. In the present study the following indicators were employed for the construction of vulnerability index.

Demographic vulnerability

There are three components involved in this index to explain the demographic patterns of the people living in the respective district.

i. Density of population (persons per square kilometer)
ii. Literacy rate (percentage)
iii. Infant mortality rate (deaths per '000 infants)

Climatic vulnerability

This index tries to take into account basic climatic variability. It combines six separate indices which are the variances of

i. Annual rainfall (mm^2)
ii. South west monsoon (mm^2)
iii. North east monsoon (mm^2)
iv. Maximum temperature ($^oC^2$)
v. Minimum temperature ($^oC^2$)
vi. Diurnal temperature variation ($^oC^2$)

Agricultural vulnerability

This includes the following variables to predict the vulnerability related to agricultural activities.

Corresponding author: Paul, K. S. R.,
Department of Agricultural Economics, Agricultural College Bapatla Guntur, Andhra Pradesh, India

i. Production of food grains (tonnes / hectare)
ii. Productivity of major crops (tonnes/ hectare)
iii. Cropping intensity (percentage)
iv. Irrigation intensity (percentage)
v. Livestock population (Number per hectare of net sown area)
vi. Forest area (percentage geographic area)

Occupational vulnerability

Six indicators were taken to calculate the vulnerability related to occupational characteristics of people and all these variables are converted into per hectare of net sown area.

i. Number of cultivators
ii. Total main workers
iii. Agricultural labourers
iv. Marginal workers
v. Industrial workers
vi. Non workers

Geographic vulnerability

i. Coastal length (kilometer)
ii. Geographical area (hectare)

Iyengar and Sudarshan (1982) developed to work out a composite index from multivariate data and it was used to rank the districts in terms of their economic performance. This methodology is well suited for the development of composite index of vulnerability to CC also. A brief discussion of the methodology is given below. It is assumed that there are *M* regions/districts, K components for vulnerability and C_k is the number of variables in component *k* so that *kic X* is the value of the variable c_k of the k^{th} component for the i^{th} region(). First, these values of vulnerability indicators which may be in different units of measurement are standardized. When the observed values are related positively to the vulnerability, the standardization is achieved by employing the formula

$$y_{id} = \left(X_{id} - Min\ X_{id}\right)/\left(Max\ X_{id} - Min\ X_{id}\right)$$

When the values of X_{id} are negatively related to the vulnerability, the standardized values would be computed by

$$y_{id} = \left(Max\ X_{id} - X_{id}\right)/\left(Max\ X_{id} - Min\ X_{id}\right)$$

where $Min\ X_{id}$ and $Max\ X_{id}$ are the minimum and maximum of $(X_{i1}, X_{i2}, ...X_{in})$ respectively. Obviously these standardized indices lie between 0 and 1. The level or stage of development of d^{th} zone is assumed to be a linear sum of y_{id} as

$$\overline{y_d} = \sum_{i=1}^{m} w_i y_{id}$$

Where w's $(0 < w < 1\ and\ \sum_{i=1}^{n} w_i = 1)$ are the weights determined by

$$w_i = \frac{k}{\sqrt{\mathrm{var}\ (y_i)}}$$

$$k = \left[\sum_{i=1}^{n} \frac{1}{\sqrt{Var(y_i)}}\right]^{-1}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter zone comparisons. For classificatory purposes, a simple ranking of the zone indices viz., y_d would be enough. However for a meaningful characterization of the different stages of vulnerability, suitable fractile classification from an assumed distribution is needed. Probability distribution which is widely used is the Beta distribution. This distribution is defined by

$$f(z) = x^{a-1}(1-x)^{b-1} / b\,(a,b),\ \ 0 \leq x \leq 1\ and\ a,b > 0.$$

This distribution has two parameters *a* and *b*. They can be estimated by using the method given by Iyengar and Sudharshan (1982). The Beta distribution is skewed. Let $(0,z_1),(z_1,z_2),(z_2,z_2),(z_3,z_4)$ and $(z_4,1)$ be the linear intervals and each interval has the same probability weight of 20 per cent. These fractile intervals can be used to characterize the various stages of vulnerability.

1.	Less vulnerable	If	$0 < y_d < z_1$
2.	Moderately Vulnerable	If	$z_1 < y_d < z_2$
3.	Vulnerable	If	$z_2 < y_d < z_3$
4.	Highly vulnerable	If	$z_3 < y_d < z_4$
5.	Very highly vulnerable	If	$z_4 < y_d < 1$

Ricardian regression model

While quantifying the impact of CC, the Ricardian type model was preferred to the traditional estimation methods, given that instead of adhoc adjustments of parameters that are characteristic of the traditional approach, the Ricardian technique automatically incorporates efficient adaptations by farmers to CC. Climate parameters considered in Ricardian models are mainly, rainfall and temperature. The carbon fertilization effects of climate change are not included. Usually climate normals, based on time series averages over a fairly long period of time are considered. The basic approach of Ricardian technique to measure the effects of CC on the value of cropland is as follows. The market value per hectare of cropland is regressed on climate and other exogenous variables to reveal the role of climate plays in explaining farm value. These climate relationships can then be used to predict the agricultural impact of future climate change. The Ricardian approach examines how climate in different places affects the net rent or value of farmland (Mendelsohn *et al.*, 1994). The most important advantage of the Ricardian approach is its ability to capture the adaptation that farmers make in response to local environmental conditions. It captures the actual response rather than the controlled ones. The relationship between area/productivity under a crop and various climatic and non-climatic variables is specified by a regression equation. The specifications used for modelling area (A_i) and productivity (Y_i) are as follows.

Ricardian type area regressions

$$A_i = \beta_0 + \beta_1 TOTCROP + \beta_2 PROCIA + \beta_3 RLT + \beta_4 RY + \beta_5 LLT + \beta_6 LY + \beta_7 HLT + \beta_8 DIUY + \beta_9 Y$$

Ricardian type productivity regressions

$$Y_i = \beta_0 + \beta_1 TOTCROP + \beta_2 PROIA + \beta_3 PROSUR + \beta_4 RLT + \beta_5 RY + \beta_6 LLT + ...$$
$$..... + \beta_7 LY + \beta_8 HLT + + \beta_9 DIUY + \beta_{10} A + \beta_{11} C_i IA + \beta_{12} PRC_i IA$$

Where, *i* = crop and other variables used above and their units of measurements are explained below.

Data on the list of crop and climatic variables give below were collected for the last 30 years and then fine tuned to 29 years by removing the missing years.

Crop variables

1. District wise Area under each crop (Ha)
2. District wise Productivity/Production under each crop (kg/ha)
3. District wise Total cropped area (Ha)
4. Total Irrigated area to total cropped area (Ha)
5. Crop wise irrigated area (Ha)

Climatic variables

6. District wise 29 year monthly rainfall (mm)
7. District wise 29 year monthly maximum temperature (o^C)
8. District wise 29 year monthly minimum temperature (o^C)
9. District wise 29 year monthly diurnal temperature variation (o^C)

Crop production is affected by many climatic variables and an attempt has been made to analyze the impact of climate change in the Ricardian sense discussed above on major crops.

In the analysis five components explained about were employed for the construction of the VI. The weather data was collected from the Indian Meteorological Department (IMD) and local statistical offices.

RESULTS AND DISCUSSION

Measuring Vulnerability of districts under Krishna river basin:

The vulnerability indices for all the 10 districts were constructed as per the methodology described earlier. Based on the indices, the districts were ranked and the rankings are given in Table 1.

Table 1. Vulnerability Index and ranks for districts under Krishna river basin

	Districts	Vulnerability index	Rank
1	Anantapur	0.614	1
2	Guntur	0.437	6
3	Hyderabad(Ranga Reddy)	0.510	2
4	Khammam	0.412	7
5	Krishna	0.465	4
6	Kurnool	0.439	5
7	Mahabubnagar	0.481	3
8	Nalgonda	0.393	8
9	Warangal	0.370	9

The vulnerability indices were subjected to further statistical analysis for classifying them into different categories. For this Beta probability distribution was fitted to the observed indices and the percentile values at 20, 40, 60, and 80 were taken as cut-off points for the five groups. This resulted in the classification as given in Table 2. The table indicates that out of the 9 districts, Anantapur district occupies rank 1 in term of vulnerability under all the three components and also overall vulnerability. The second rank is occupied by Ranga Reddy in terms of vulnerability. Warangal district is least vulnerable among the districts of Krishna basin. It has a very vulnerability index of 0.3706.

Table 2. Classification of districts under Krishna river basin in terms of Vulnerability

S. No	Classification	Districts
1	Less vulnerable	Nalgonda Warangal
2	Moderately vulnerable	Kurnool , Guntur Khammam
3	Vulnerable	Krishna
4	Highly vulnerable	Hyderabad (Ranga Reddy) Mahabubnagar
5	Very high vulnerable	Anantapur

Impact of climate change on the area of crop

The variables Annual rainfall (RY), Long-term rainfall average (RLT), Long term daily minimum temperature average (LLT), Long term daily maximum temperature average (HLT) and yield of paddy were significant independent variables in affecting the area of paddy. Further, annual rainfall (RY), long term daily minimum temperature average (LLT) and yield of paddy had positive significant effects on the area of paddy. But, the long term daily maximum temperature average (HLT) and long term rainfall average (RLT) will significantly reduce the paddy area. In case of paddy, the model is adequate as indicated by the F-statistics of the ANOVA. The R - square value is 0.72 implying that 72% of the variation in the area under paddy. One unit increase in the variable RY, LLT and Yield of paddy will increase the area of the paddy by 56.33, 161230.84 and 12.681 ha respectively keeping the other variables constant. The result implies that the paddy crop is profitable and the paddy area increased under these climate variables. It can be noted that long term daily minimum temperature average (LLT) has maximum effect in increasing the area under paddy. Unit increase of these will likely result in decrease of 95364.89 and 146.86 ha of paddy area respectively. Thus the climate variables such as long term daily minimum temperature average and long term daily maximum temperature average are important determinants of paddy crop.

In case of maize, the model is adequate as indicated by the F-statistics of the ANOVA. The R-square value is 0.19 implying that 19% of the variation in the area under maize can be explained by the model. The variables TOTCROP, RLT, LLT, HLT and Yield of maize are significantly affecting the area of maize. The variables TOTCROP, RLT, HLT and yield are positively significant and the long term daily maximum temperature average (RLT) has maximum positive effect on the area under maize i.e., one unit increase in the variable results in increase in the area of maize by 28245.11 ha, whereas long term daily minimum temperature average (LLT) has maximum effect in reducing the area under maize by 25935.69 ha for one unit increase in the variable. In case of groundnut, the model is adequate as indicated by the F-statistics of the ANOVA. The R - square value is 0.85 implying that 85% of the variation in the area under groundnut. The variables TOTCROP, PROIA, LLT and HLT are significantly affecting the area of groundnut. The variables TOTCROP and PROIA are positively effecting and the variable TOTCROP has maximum positive effect on the area of the groundnut .One unit increase in TOTCROP and PROIA will increase the area of groundnut by 0.537 and 553.33 ha respectively. Similarly, the variables HLT and LLT will significantly reduce the area of the groundnut. One unit increase in HLT and LLT will reduce the groundnut area by 154957.42 and 112172.10 ha respectively. The variables TOTCROP and HLT are the important determinants of groundnut area.

Table 3. Ricardian Area regression result

Variable	Paddy	Maize	Groundnut
Constant	-7406.542	-429229.092	6996333.3
	(275437.35)	(98619.97)	(368422.64)
TOTCROP	-0.005	0.046***	0.537***
	(0.035)	(0.013)	(0.048)
PROIA	25.665	52.945	553.331***
	(92.050)	(32.98)	(123.46)
RLT	-146.868**	156.011***	65.193
	(79.88)	(28.64)	(107.37)
RY	56.338***	-5.712	-29.949
	(17.04)	(6.15)	(22.94)
LLT	161230.845***	-25935.693***	-112172.100***
	(16619.47)	(5890.81)	(22489.01)
HLT	-95364.895***	28245.113***	-154957.428***
	(14387.53)	(5133.56)	(19240.03)
HY	-12031.940	-2259.933	8226.769
	(7906.76)	(2842.79)	(10653.95)
DUIY	18177.405	-1172.741	9660.648
	(11394.73)	(4113.25)	(15310.03)
Yield	12.681***	3.708***	1.090
	(4.66)	(0.903)	(10.57)
R^2	0.725	0.191	0.86
F-stat	73.65	6.57	171.44

*** indicates significance at 1% and ** indicates significance at 5%

Table 4. Yield Regression Results

Variable	Paddy	Maize	Groundnut
Constant	-2411.473	-2781.106	-924.985
	(5878.46)	(6919.08)	(3536.48)
TOTCROP	0.000	0.000	0.000
	(0.00)	(0.001)	(0.00)
PROIA	0.936	0.284	0.588
	(1.258)	(1.955)	(0.739)
PROSUR	-7.761**	-26.773***	-0.892
	(3.964)	(6.810)	(2.250)
RLT	-2.220	-5.923***	-1.954***
	(1.373)	(1.819)	(0.645)
RY	0.178	0.718**	0.214
	(0.231)	(0.362)	(0.131)
LLT	615.371**	1892.86***	572.930***
	(304.00)	(454.24)	(163.26)
HLT	-329.516	-954.148***	-177.202
	(232.54)	(354.26)	(141.44)
HY	-69.089	23.196	-101.691
	(106.16)	(171.46)	(63.11)
DUIY	79.949	14.138	-8.387
	(152..82)	(248.20)	(89.50)
CA	0.036**	-0.014***	0.001
	(0.016)	(0.006)	(0.00)
CiA	-0.035**	0.100***	-0.005**
	(0.016)	(0.015)	(0.003)
PRCIA	57.599**	6.641	10.277***`
	(26.43)	(4.878)	(2.167)
R^2	0.181	0.402	0.324
F-stat	4.564	13.91	9.903

*** indicates significance at 1% and ** indicates significance at 5%

The impact of climate change on the productivity of crop

The selected variables LLT, Area of paddy and PROCIA were significant and positive affecting the productivity of paddy (tab.3). The variables PROSUR and CIA have negative significant effects on productivity of paddy. One unit increase in the variables LLT, PROCIA and Area of paddy, the productivity of paddy increases by 615.37, 57.59 and 0.036 kg/ha. Similarly, unit increase in the variables PROSUR and CIA reduces the yield of paddy by 7.76 and 0.035 kg/ha respectively. All these variables are significant at 1% level. In case of maize, the variables the LLT, CIA and RY are positively significant affecting the productivity of maize crop. One unit increase in these variables increases the productivity of maize by 1892.86, 0.100 and 0.718 kg/ha respectively. Similarly the variables PROSUR, RLT, HLT and Area under maize crop are negatively affecting the maize productivity i.e., one unit increase in these variables reduces the yields by 26.77, 5.92, 954.14 and 0.014 kg /ha respectively. All the variables affecting maize productivity are significant at 1% except RY which is significant at 5%. Thus, the irrigation variables CIA and PROSUR are important determinants of maize productivity. In case of groundnut, the variables LLT and PROIA are positively significant affecting the productivity of groundnut. For one unit increase in these variables, the productivity of groundnut increases by 572.93 and 10.277 kg/ha respectively. Similarly the variables CIA and RLT are negatively significant affecting the groundnut productivity i.e., unit increase in these variables reduces the productivity of groundnut by 0.005 and 1.954 kg/ha respectively. All the variables are significant at 1% except CIA which is significant at 10% level.

Conclusions

The present paper provides the classification of districts of Krishna river basin into different categories of vulnerability. The study has identified Anantapur district as very highly vulnerable and two districts namely Nalgonda and Warangal as least vulnerable. This conclusion will very much useful for planning suitable remedial measures to mitigate the effects of climate change. The Ricardian regression area results revealed that the climate variables such as long term daily minimum temperature average and long term daily maximum temperature average are important determinants of area of paddy crop. The climate variables long term daily maximum temperature average and long term daily minimum temperature average (LLT) has maximum effect. The variables TOTCROP and HLT are the important determinants of groundnut area. The Ricardian regression yield results revealed that the LLT and PROSUR are important determinant of paddy productivity and the variables LLT and HLT are important determinants of maize productivity where as in case of groundnut RLT and LLT are the important variables influencing the groundnut productivity.

Recommendations

The Vulnerability Index is emerging as a promising planning tool for climate change adaptation at river basin level. Using the results of the Vulnerability index (VI) of the districts, the adaptation practices being practiced in the extreme situations has to be documented. This would provide indications to similar currently non-vulnerable districts of locations in which to study successful societal adaptation. Awareness has to be created on climate change and adaptation methods to overcome the extremities of climate change. Facilitating the availability of credit to the farmers during the critical climatic conditions to go for new technologies or adaptations. In case of individual farm level measures such as early sowing at farm ponds, soil moisture conservation by in-situ green manure crops etc can be very useful to conserve water. To achieve better results, participatory approach involving all possible stake holders viz., farmers organizations, water users associations, department of agriculture, department of irrigation, district water management agency, NGOs etc. has to deserve special attention. This facilitates the researchers to plan the water management strategies more effectively and efficiently so as to combat the declining economic efficiency of irrigation water resources in NSP right canal command area.

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