Assessing the projections of crops yield due to climate change with reference to actual yield- a review on Indian perspective

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Abstract

Agriculture is the most weather dependent human activity. The present study has reviewed existing literature to document evidences relating to the impact of climate change on yield of various crops in India for providing insights on status of projected vis-a-vis actual estimates based on difference in methodology used in the studies and other factors which affect the yield of those crops. The reasons behind the deviations could be variation in methodology used in the studies, differences in the variables chosen for estimations in the model. Some of the factors have not been considered in one or the other study which made their projections vary based upon the assumptions made in their studies. The adaptation measures like release and adoption of new varieties of crops and increase in area under irrigation, use of more chemicals and fertilizers, improved mechanizations of agricultural operations etc. have contributed in enhancing the yield of crops. These measures shall uplift the yield of crops in India and should be strengthened by the government for sustainable agriculture.

Keywords: Climate change, agriculture, impact, deviations, projections

Introduction

In India, the agriculture sector employs about 45 per cent of the workforce of the country and has strategic importance for ensuring food security of huge human population although its share in national income has been declining with development of Indian economy[1]. Therefore, the steady growth of agriculture is must for progress of the country. Agriculture is weather dependent activity in India and nearly 48 per cent of the total cropped area is still dependent on the uncertainties of monsoon rainfall [2,3]. Weather plays an important role in determining growth of crops and their yield. Even minor changes in the normal weather hinder the efficiency of crop production. Climate change through changes in temperature and precipitation affect the soil conditions, salinization and soil water content therefore, it may impact agricultural production negatively which have grave consequence for human society.[4].

Changes in agricultural policies, uncertainties in market, terms of trade, availability of water resources, and the uncertainties driven by climate change including droughts and floods influences the performance of agriculture sector and its production[5]. The changes in climate occurs due to increase in temperature on account of rising level of greenhouse gases in the environment such as carbon dioxide, ozone, methane, nitrous oxide and chlorofluorocarbons. Since agriculture sector is also one of the contributors of greenhouse gases and get affected badly with change in temperature, concentration of carbon dioxide and rainfall pattern, more concern is given to the climate change and its effect on agriculture in future[6-12].

A large number of studies have been conducted to analyse the impact of climate change on agriculture in India and around the globe, many of them have projected changes in crops yield

due to climate change in short run and long run. In order to understand whether the projections made by the researchers on the impact of climate change on crop yield are close to actual yield or at variance, the study examined the projections on changes in crops yield in India up to the year 2020 and compared with the actual data. Moreover, it is also essential to understand the underlying reasons for deviation in actual yields from projected one. The study further explores the efforts of the government and other stakeholders including researchers, farmers and development agencies those are working to minimise the negative impact of climate change. The discussion on the above issues will improve the understanding the of climate change on agriculture and help in designing the appropriate adaptation strategies to deal with future impact of climate change on Indian agriculture.

Methodology

The study reviewed the literature available on projections of crops yield due to the impact of climate change across regions in India. Out of those only seven studies projected the crops yield due to climate change up to the year 2020s and hence selected for the further analysis. The projected yield of various crops across regions was taken from the studies reviewed. Most of these studies have projected changes in yield in percentages from base line and some of them have also provided both the base line yields and projected yield. The actual estimate of the yield for the crop of the region was taken from the period starting from 1966 till 2020 from DES. The trend line of actual crops yield was fitted to see whether actual data shows declining or increasing trend over the period to compare with the projected decline or increase in crops yield due to climate change.

Climate change and crop production

Climate change and its impacts have been widely recognized as forefront of the policy discourse in India. The effect of climate change could be negative or positive on the yield of crop which depends on the type of crop and environmental conditions[13]. The general consensus is that there will be adverse as well as favourable effect of climate variability on region-specific agriculture in the absence of suitable strategies to deal with climate change. Some of the impacts will be slow which will enable the farmers and government to respond with their strategies, however, some of the climate change variables will have unexpected outcomes on agricultural productivity which may not be known easily or the strategies and resources could not be put forward. The intensity of droughts, storm damage and flooding are expected and the impacts of climate change on the agricultural productivity are projected. Extreme conditions of weather such as droughts, floods, hailstorm and cyclones are direct threats to crop cultivation. Moreover, the minuscule changes in weather during vital phases of crop development can also have considerable impact on yield of crop production. Climate change may have some impact indirectly on the harvested areas. For example, a 19 per cent decline in summer monsoon rainfall in 2002 resulted in 18 per cent decline in foodgrains production in India during 2002-03[14].

An extensive literature has addressed the impact of climate change on agriculture which identified a wide range of factors influencing vulnerability of agriculture such as type of crops grown, awareness of the climate variations, soil content, financial constraints, and ability to adopt the remedial measures relating to climate change. It has been estimated that decline in rice yield was lower in east India as compared to all the other regions[15]. Mean grain yield of control crop was 7.9 t ha^{-1} in eastern region as compared to 8.7-9.9 t ha^{-1} in other region in India. The southern and western part of India having relatively low temperatures are likely to have less rise in yield of rice in improved management conditions under the climate change as compared to the

north and east regions of India. The effect of rainfall on yield of irrigated crop varies with the location[16]. An increase in temperature with elevated CO_2 will generally lead to rise in yield of soybean in the region[17]. A study conducted using the crop simulation modeling approach concluded rise in minimum temperature and negative trends in solar radiation which resulted in decline in potential yields of wheat and rice in the Indo-Gangetic Plains in India[18]. The decline was 356 kg ha^{-1} $decade^{-1}$ in rice yield for PRECIS output and decline of 217 kg ha^{-1} $decade^{-1}$ for RegCM3 output without considering CO_2 fertilization effect[6]. However, with CO_2 fertilization effect, decline was 135 kg ha^{-1} $decade^{-1}$ for PRECIS output and increased yield of 24 kg ha^{-1} $decade^{-1}$ for RegCM3 output.

It has been estimated that the rice yield would increase in south and central India by the middle of the next century[19]. Moreover, the yield would decline in the north-west region under irrigated conditions as a result of decline in rainfall during monsoon season. But the increase in rainfall in Kerala makes up for the negative impact on yield of rice due to rise in temperature[20]. However, the increased CO_2 concentration causing any possible gain would be offset by the decline in yield generated by shorter growing period and higher temperature[21]. While rice yield is at risk to rise in minimum temperature, the wheat yield is sensitive to the rise in maximum temperature[22]. Moreover, there is variation in impact of climate change on yield of sugarcane across states in India due to geographical location, diversity in climatic factors, natural resources, irrigation facilities, use of advance technologies and fertilizer, farm management practices, agricultural research and development and agricultural development policies[12].

Projected vis-à-vis actual yield of crops

As climate change will result into rise in temperature, changes in rainfall and other climatic variables, researchers have projected its impact on various crops for the future. Table1

presents the projected yield of various crops in different regions of India and figure 1, 2 and 3 presents the trends in actual yield of crops over time. The two studies[23, 24] conducted in Tamil Nadu by using panel data approach and Ricardian approach have projected decline in the yields for 2020s over the base year. However, the actual yield of rice, sugarcane, paddy, groundnut and sorghum has increased over the period as depicted with the trend line (figure 1and 2). Moreover, in case of maize, the yield was projected to increase due to climate change and actaual yield has also increased over time r(figure 3) . A study in Gomti river basin[25] and Bhavani Basin[28] using Soil and Water Assessment Tool (SWAT) projected yields of rice and wheat for the year 2020. Comparison with actual data reveals that the actual yield of rice and wheat has increased more as compared to the projected one. The yield of wheat has been increasing due to the fact that wheat was irrigated using shallow aquifer water which has thwarted the adverse effect of decrease in rainfall[25]. A study in Punjab[26] also reveals that the actual yields of rice and wheat have increased over as against the projections of decline due to climate change (figure 1). Using InfoCrop model a study[27] projected decline in rice yield during 2020s in India, where as actual yield showed increasing trend over time in various regions as well as for All India. The study[29] conducted using InfoCrop model has shown increase in projected yield in 2020 over the base period moreover the trend in actual yield shown higher increase as compared to the projected one. Therefore, it can be clearly seen that the actual yield has increased more as compared to the projected decline or rise in yield as depicted by the linear trend. The yield has increased due to the increase in rainfall in the regions which had affected yield of crops positively. The above studies have pointed out the impact of climate change on different crops in India. Moreover, there is variation in the methodology used in various studies.

From above discussion, it is clear that, projections on crops yields due to climate change in all the studies for the 2020 have deviated from the actual yields and in most cases actual yield remained higher than the projected one. Thus it is important to explore the reasons behind such differences in actual and projected crops yield. The probable reasons could be problems in methodology used in the studies, variables selection for the estimations in the model or various adaptations measures taken by farmers and policy initiations by policy makers of the country. Adaptation measures in the form of introduction of improved varieties of crops for higher yield and abiotic stress tolerance increase in area under irrigation, micro irrigation techniques, more farm power availability, increase in credit availability and enhanced use of inputs.

One of the important methodologies used in the studies[27, 29] is crop simulation method which does not include adaptation to climate change conditions by the farmers and moreover it can overstate the damage caused by changing climate[30]. However, the Ricardian approach applied by researcher[24] uses cross-sectional data but fails to take account the time-independent location specific factors such as soil quality[23] which could cause the deviations in actual and projected figures. Moreover, the estimates are hindered by unavailability of land prices. In addition to these approaches, researchers have used panel data approach in their studies[23, 26] which has large number of unknown parameters in the error process resulting in unreliable estimates of the standard errors of estimated coefficients[23]. SWAT model has been applied in few studies[25, 28] which helped in developing the adaptation strategies to sustain the productivity of crops. Therefore, the methodological limitations could probably be one factor for projection of yields which could not match with the actual yield data across regions in the country.

Further exploration of the above studies provides insights of the variables used in the analysis in the model. A study has pointed out the increase in rice yield due to rise in rainfall

during end of the century which clearly indicates rainfall as an important factor which impacts the agriculture production. The model uses maximum and minimum temperature, daily precipitation, solar radiation, relative humidity and wind speed in the study conducted in Gomti River Basin[25]. However, the study in other states and all India level[27] considers the location-wise daily data on solar radiation, rainfall, maximum and minimum temperature, vapour pressure and wind speed. An analysis by Ricardian approach in Tamil Nadu[24] considered annual rainfall, maximum and minimum temperature and diurnal temperature variation in their study whereas the other study in Tamil Nadu[23] used normal rainfall which is moving average of five years (because farmers adapt to the climate change in agriculture over the time) and mean temperature to examine the impact. Such studies can be improved by including some additional factors such as amount of reservoir water for irrigation. Researchers using panel data in analysis in Punjab[26] had considered monthly minimum and maximum temperature and rainfall data to assess the impact of climate change. Swat model in the study[28] has considered solar radiation, maximum temperature, minimum temperature and rainfall while maximum and minimum temperature, rainfall, soil information and varietal parameters has been used in the study in Bihar[29]. Therefore, studies have considered different factors to assess and make projections of climate change impact on agriculture sector which might cause the difference in the projected and actual yield during 2020s.

However, strengthening the process of adaptation is the logical option to deal with the extremes of climate change. Different adaptation measures have been suggested in various studies to reduce the impact of climate change on agriculture in India. Stress tolerant high yielding crops variety[27,31,32], crop insurance, easy availability of credit, irrigation facilities[23, 25], agronomical management[27] such as intercropping, crop diversification and mixed cropping

techniques and modern inputs should be used by the farmers to deal with the losses in yields of different crops due to climate change[10]. Irrigation[32, 33] can negate the harmful effects of climate change on rice, groundnut, wheat and rapeseed-mustard crops[34]. Moreover, change in planting dates[35] and varieties, adopting crop management strategies[27], high input delivery[32,36], development of adverse climate-tolerant genotypes and land-use systems, risk management through crop-weather insurance, improved land-use policies[37], location-specific needs[38] and application of bio-fertilizer[33] increase the adaptive capacity of the crops. The farmers in Tamil Nadu, Karnataka and Kerala should adopt soil moisture conservation, provision for nutrient supply, proper drainage[36] to reduce the impact of climate change. The improved wheat varieties[35] be sown along with better nutrients and irrigation as well as the higher dose of nitrogenous fertilizer[27, 35] is essential to sustain the yield in future[39].

Adaptation measures taken to curtail the impact of climate change

The stakeholders in crop production, such as farmers, researchers and development agencies have contributed in developing adaptation strategies and policy due to which adaptation measures have been adopted which has curtailed the impact of climate change on agriculture. As a result of these adaptation measures, there has been improvement in yield of crops in India despite of the projections of decline in crops yield due to climate change. The figures 1, 2 and 3 indicate the increasing trend with some fluctuations in yield of crops in the states as well as All India over the period. Farmers possess the knowledge about climate and agriculture which lead them to take the adaptation decisions to reduce the losses against the change in climate. Farmers have made changes in planting and harvesting dates and adopted high yielding varieties that are less water consuming and drought/heat tolerant. Farmers have adopted improved farm machinery which has enhanced the input use efficiency.

Government of India has taken a number of initiatives to improve the availability of quality inputs for improving their uses at farmer's field which will be able to improve the crop yield and curtail the adverse impact of climate change on crops yield. Due to government efforts, availability as well as use of agricultural inputs and like fertilizers, quality seeds, pesticides and use of agricultural credit have improved over time. The details of the same during recent year are provided in the table 2. It is clear from the table that the consumption of chemical fertilizers and pesticides has increased between triennium ending 2009-10 and 2019-20 on all India bases as well as in the states of Punjab, Bihar and Uttar Pradesh except for Tamil Nadu. Bihar has registered a significant increase in the consumption of fertilizers (59.51 kg/ha) during the periods. Moreover, the distribution of quality seeds and the agricultural credit disbursed by bank has shown rapid improvement which might probably have helped in enhancing the yield of crops despite the climate change in India.

It is important to note that there has been increase in area irrigated under crops in different regions as depicted in table 3. The area irrigated has increased by 8.09 per cent under rice crop in India. The percentage area irrigated has shown quantum increase from 70.11 per cent to 86.26 per cent for rice crop in Uttar Pradesh. Bihar has also shown improvement in area irrigated with 13.37 per cent point change as the crop is grown under irrigated conditions without any water stress[28]. The micro-irrigation technique addresses the problems of emission of greenhouse gases and water scarcity in agriculture. The sprinkler system is most suitable for field crops which increase the efficiency of water use to the extent of 50-90 per cent. Punjab has the highest groundwater development of 149 per cent which is subsequently followed by Rajasthan with 140 per cent[44]. Tamil Nadu, Gujarat, Maharashtra, Karnataka and Andhra Pradesh together dominate total drip-irrigated area and Karnataka and Rajasthan dominates in case of sprinkler

system[3]. Apart from this, many improved cultivars of crops have been introduced by state and Central government which may have contributed in improving the yield of crops in particular regions as given in table 4.

Moreover, farm mechanization has played an important role in climate proofing of agriculture.. In view of present challenges throughout the production system, the future growth has to come from the acceleration in the rate of farm mechanization[45,46]. In recent years, the pace of farm mechanization has improved tremendously and farm power availability has increased from mere 1.87 kW /ha in 2011-12 to 2.76 kW in 2020-21[47]. This has led to enhancement in yield of crops.

Conclusion

There are evidences in the literature on increasing trend in the climatic variables in India over the years. This has resulted in affecting the performance of agriculture sector. An extensive literature has been discussed in the study which outlines the deviations in projected and actual yield of crops in India. Soora et al. (2013)[27] and Haris et al., 2010[29] has used InfoCrop model, Palanisami et al. (2009)[24] assessed the impact by Ricardian approach, Saravanakumar (2015)[23] and Kumar and Sidana (2019)[26] has used panel data approach and Abeysingha et al. (2016)[25] and Lakshmanan et al. (2010)[28] has considered SWAT model which have their own different assumptions. Abeysingha et al. (2016)[25] has projected very near to accurate estimates. However, it is clear that yield projections in all the studies are lower than the actual yield over the period. This deviation in projection from actual yield may be due to methodological issues or adaptation strategies adopted by farmers as per suggestions of researchers and Government of the country. The adaptation measures like stress tolerant variety seeds, crop insurance proper credit, irrigation facilities, agronomical management, modern inputs, irrigation, change in planting dates and

varieties adopting the crop management strategies, high delivery input delivery, development of adverse climate-tolerant genotypes and land-use systems, risk management through crop-weather insurance, improved land-use policies, location-specific needs, application of bio-fertilizer, provision of nutrient supply, proper drainage and soil moisture conservation. These measures shall uplift the yield of crops in India and adapt the agriculture to climate change and hence require more emphasis to address the climate change issue in Indian agriculture. The adaptation of climate change to agriculture should take into account long-term decision making and introduce incentives to change behavior in response to climate change for the proactive adaptation. The human capital needs to be strengthened through education, extension services and improvement in the decision making capacity. However, the most vulnerable region should potentially adapt by diversifying the agriculture with less water intensive crops, constructing roads and dams and adopting the farm technology like irrigation pumps, crop variety and use of harvester[48].

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Acknowledgement

Authors are thankful to the Director, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi for providing facilities to undertake the study. The study is a part of NICRA project being sponsored by ICAR, New Delhi.

Table 1: Projected changes in crops yield due to climate change in India

Reference	Methodology used for projection	Base year	Year for the projection	Region/ state	Projected Yield (q/ha) during 2020			
					Crop	Base period yield	Change in yield projected (%)	Projected Yield
Saravanakumar (2015)	Panel data	1971-2009	2011-20	Districts of Tamil Nadu	Rice	27.72	0.55q/ha ↓	
					Sorghum	10.28	0.75 q/ha ↓	
					Maize	17.46	0.29 q/ha ↑	
Palanisami et al., 2009	Ricardian model	1990-2001	2020	Districts of Tamil Nadu	Paddy	33.97	3.52 ↓	32.78
					Sugarcane	839.3	13.40 ↓	726.80
					Groundnut	17.45	7.04 ↓	16.22
Abeysingha et al., 2016	Soil and Water Assessment Tool (SWAT)	1995-2002 (rice) 1996, 1998-2003 (wheat)	2020s	Gomti river basin	Rice		5.5-6.7 ↑	
					Wheat		13.9-15.4↑	
Kumar and Sidana (2019)	Panel data 2020	1986-2015	2020	Districts of (Punjab)	Rice		2.56 ↓	
					Wheat		1.93 ↓	
Soora et al., 2013	InfoCrop model	2000-07	2020 (2010-2039)	All India	Rice		~4 (irrigated)↓ ~6 (rainfed) ↓	
				Punjab			6-8 (irrigated)↓	
				AP			3-22 (rainfed)↑	
				Chhattisgarh			8-10 (rainfed)↓	
Lakshmanan et al., 2011	SWAT model	1971-2010	2011-2040	Bhavani Basin	Rice	47.62 42.16	Kharif 3.15↓ Rabi 16.63↑	46.12 49.17
Haris et al., 2010	InfoCrop model	2006-08	2020	Patna (Bihar)	Rice	44.11	2.7 ↑	45.32

Source: Authors compilation based on studies reviewed**.**

Table 2: Status of climate adaptation measures in agriculture

Particulars	TE 2009-10	TE 2019-20	Change (%)
Distribution of certified/ quality seeds (million q)	21.73	35.25	134.72
Consumption of pesticides (1000' tonnes)	42.44	61.59	19.15
Fertilizers consumption (kg/ha):			
Tamil Nadu	200.56	167.90	-32.67
Punjab	222.82	227.11	4.29
Bihar	169.13	228.64	59.51
Uttar Pradesh	158.96	172.89	13.93
All India (Average)	126.97	131.19	4.21
Agricultural credit distributed by scheduled commercial banks (billion Rs.):			
Bihar	84.67	395.53	310.86
Uttar Pradesh	347.00	1365.84	1018.84
Tamil Nadu	348.33	1637.10	1288.77
Punjab	175.00	692.89	517.89
All India	3246.33	13056.99	9810.65

Source: Agricultural statistics at glance data 2007-08 to 2019-20

Table 3: Crop wise area irrigated and growth rate

State	Crop	% area irrigated		%age Change over time
		TE 2002-03	TE 2018-19	
India	Rice	53.42	61.51	8.09
Punjab	Rice	99.29	99.62	0.33
	Wheat	97.95	99.16	1.21
Uttar Pradesh	Rice	70.11	86.26	16.15
	Wheat	96.45	98.97	2.52
Tamil Nadu	Rice	92.34	92.97	0.63
	Sorghum	10.21	9.93	-0.27
	Groundnut	32.88	39.12	6.25
	Maize	31.47*	33.68	2.21
	Sugarcane	100.00	100.00	0.00
Bihar	Rice	54.36	67.74	13.37

Source: Land use statistics at a glance data 2000-01 to 2018-19[40].

Note: Due to data inconsistency of area irrigated under maize crop in Tamil Nadu, triennium ending 2004-05 is taken.

Table 4: Improved crop varieties released for across regions in India

Crop	Region/state	Varieties
Rice	UP	CR Dhan 501, Chinsurah Rice, US 312, NDR 2065, CSR43, TPS 5, Shiats Dhan-1, Shiats Dhan-2, Shiats Dhan-3, Shiats Dhan-4, Shiats Dhan-5, Narendra Lahar and Narendra Parag, Pant Basmati 1, Pant Basmati 2, Pusa Basmati 1609, Sukhadhan 5 and Sukhadhan 6, 28P09, 28S41, CO 51, DRR Dhan 50, 28P67, BIO 799, CR Dhan 909, CR Sugandh Dhan 908, DRR Dhan 51, HRI 183, NPH 8899, VNR 2228, CSR 56 and CSR 60, CSR 46 and ADT 51
	Tamil Nadu	CR Dhan 501, Chinsurah Rice, US 312, CO (R) H-4, CR 1009 Sub 1, TKM 13, MDU 6, Indira Aerobic 1, Chandra, KPH 460 and ADV 8301, 28P09, 28S41, CO 51, DRR Dhan 50, Co-43 Sub1, CO 52, CR 1009 Sub 1 and MDU 6, CSR 46 and ADT 51
	Punjab	PR 123, Pant Basmati 2, Pusa Basmati 1609, Chandra, 27P22, HRI 180 and Pusa Basmati 1718, PR-126, Punjab Basmati-4 and Punjab Basmati-5, VNR 2111 Plus
	Bihar	CRL 22, CR Dhan 701, US 312, Sabour Surbhit, Sabour Shree, Chandra, Sukhadhan 5, DRR dhan 46, 28P67, Rajendra Nilam, MRP 5408
	All India	VNR-2111, CO 51
Wheat	UP	Phule Satwik (NIAW 3170), KRL 283, DBW 173, Pusa wheat 1612, HUW 669, AAI-W9, WB 02,
	Punjab	Phule Satwik (NIAW 3170), DBW 173, WB 02, Unnat PBW 343, PBW 1Zn
Sorghum	Tamil Nadu	CSH 38, CSH 37, K 12
Maize	Tamil Nadu	ADV 759, ADV 757, Baby corn GAYMH-1, Ladhowal Popcorn, GAPCH-21 Mahashweta, AH 7043, CO 32, CP 999, MH 9344, P 3401, HTMH 5402
Sugarcane	Tamil Nadu	CoC 13339, Sankalp
Groundnut	Tamil Nadu	Girnar 4, Girnar 5, GJG 33, VRI 8, GJG 32

Source: Various annual reports [41,42,43]

Figure 1: Trends in actual yield of the crops in the states showing increase in projected yield due to climate change

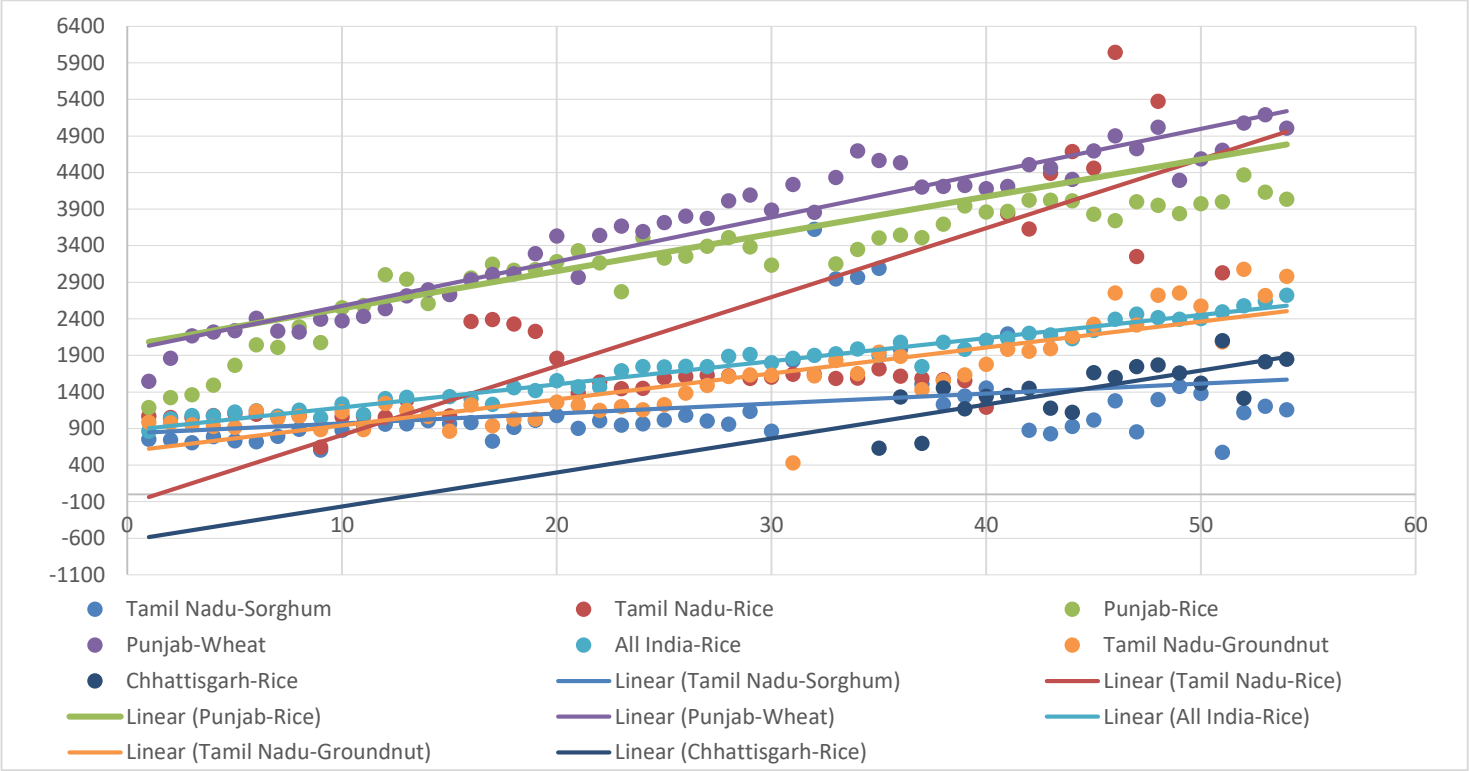

Figure 2: Trend in yield of sugarcane in Tamil Nadu over the period

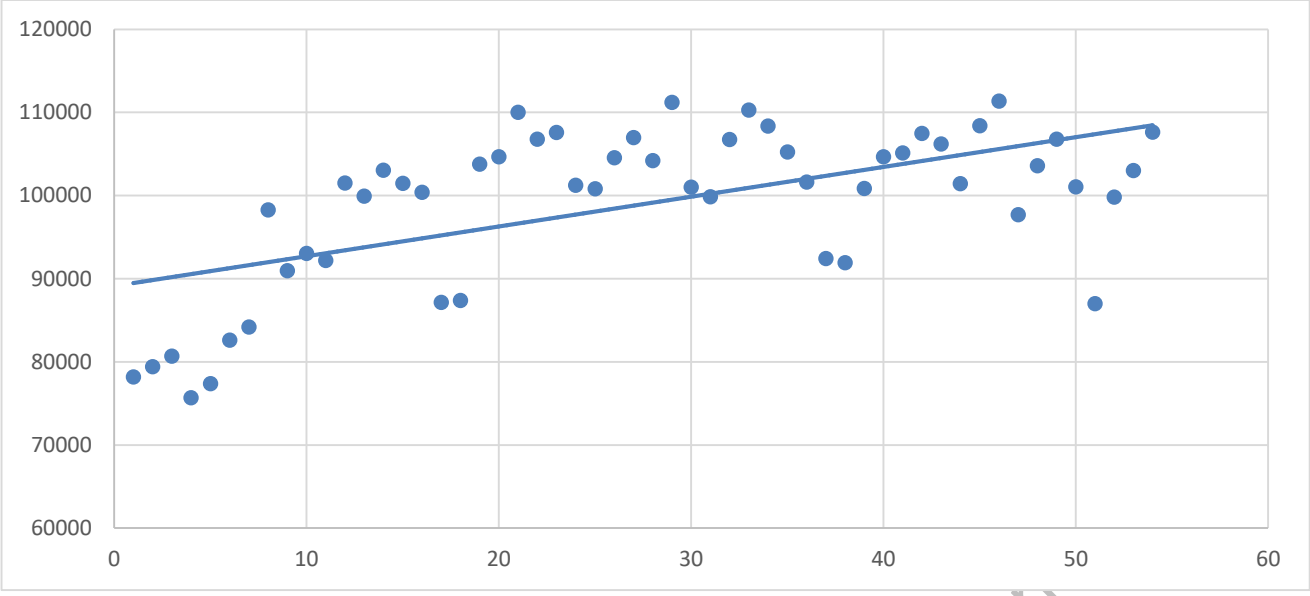

Figure 1: Trends in actual yield of the crops in the states showing decline in projected yield due to climate change