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Impact of climate change on rice yield of Bargarh District: The rice bowl of Odisha

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Abstract
Climate plays a pivotal role in crop growing period, crop production and productivity. The change of climate with time demands adoption of new package of practices and technologies. This requires knowledge of impact of weather variables on the crop over the years. Based on this pre-requisite knowledge; the new technologies or policies could be developed and implemented. The impact of weather variables on crop yield can be assessed through the use of multiple linear regression technique. The traditional average method of weather variable over the cropping period and the weather indices have been used to study the impact. Impact of individual weather parameters has also been studied through hierarchical partitioning of total R^2 to component R^2. The study shows that in Bargarh district, relative humidity has a positive significant effect whereas minimum temperature has significant negative effect on yield of rice when traditional averaging of weather parameters and weather indices are considered.

Keywords: R^2, Shapley R^2 contribution, climate change, multiple linear regressions, weather indices, yield

1. Introduction

Human evolution with time prospers in cultural, technological, scientific, economic, and agricultural production. Agricultural revolutions influenced the advancement of the human race. However, the incredible population explosion requires food security for survival. By 2050, the demand for food production will be doubled (Tilman *et al.*). Enhancing crop yield is recommended for food security rather than creating more land surface (Goldfrey).

Agriculture is the day-old human practice on which the economics and sustainability of a country depend heavily. Today, agriculture is not only a regular practice; for producing foods but also generates employment, provides nutritious value to human health, and significantly contributes to Gross Domestic Product (GDP). For India, contribution of agriculture to GDP is 16% in fiscal year 2024 (Economic survey, 2024-25). In 2024-25, the contribution to Gross Value Added (GVA) was 17.4% through agriculture and allied sector (Economy Survey 2024-25), where GVA is defined as addition of GDP with subsidies on products and subtraction of taxes on product from it. Agriculture generates 54.6% of employment in India in its 131-crore population (Census, 2011) with a projection of 145 crore in 2024 (The United Nation Population Fund). With the fragmentation of land holding, depletion in groundwater, and other ecological factors, food production and food security face different challenges to a new regime. Cereals play a vital role in food security for India.

Rice is a prominent principal cereal food for 50% world's population. Asia is the highest producer and consumer of rice in the entire world. The total rice production in the world is 488.60 million metric tons (USDA, 2017). India spots second after China in production with 165.3 million metric tons, whereas China produces 210.10 million metric tons (Statistica, 2017).

Odisha constitutes ten agro-climatic zones with thirty districts. The people of Odisha consume rice as their staple food. The farmers of the State show less interest in agricultural activities due to shared environmental and biological hazards. Odisha survives cyclones almost every year.

The climate change scenario is reflected very well in the form of erratic rainfall, late onset of monsoon, rise in temperature, which readily affects the rice life cycle from sowing to harvesting stage, easy emergence of significant pests, and decline in natural enemies.

In Odisha, most of the population consumes rice as a staple food. Rice is the primary agricultural commodity in Odisha. It is the farming fraternity's oldest income source. The production of rice needs to be increased to meet the demand of growing population every year. Earlier agriculture production was carried out in large cultivated areas, whereas now-a-days, urbanization diminishes the cropping area. Moreover, disengagement of the farmer fraternity from doing agriculture for several reasons like environmental calamities (drought, flood, etc.), ecological stress (pest and disease attack), stress due to non-availability of marketing place, increase in cost of cultivation and lack of stimulation to the farming community are significant causes of less production.

Bargarh district of Odisha is known as rice bowl of the state. Since 1950, the cultivation and production of rice was surged after Hirakud reservoir water was channeled through canal for irrigation purpose. Application of fertilizers and pesticides became a boon with time. The blooming production was also impacted with time due to global climate change situation. The climate change induces surge of biotic stress like pest, disease and weeds. The effect of climate change on yield of crop can be studied through establishing a linear relationship between them. Multiple linear regression will reflect the amount of variation of yield by different climate parameters and their individual impact on yield. This research will study the impact of climate change on rice yield of Bargarh district. To understand the impact of climate variable on yield, two types of studies has been carried out. Firstly, the multiple linear regression of yield on average values of weather parameters like precipitation, maximum temperature, minimum temperature and relative humidity for the kharif period i.e from July to October since 1993 has been carried out and secondly, starting from pre-sowing period to harvesting period the weekly data has been converted to yearly representation of climate data in the form of indices and then multiple linear regression of yield on weather indices have been evaluated.

2. Materials and Methods

2.1. Source of Data

The yield data of the different districts for the study selected have been obtained from Department of Agriculture and Farmers' Empowerment, Government of Odisha (GoO). In Bargarh district, rice is grown in *Kharif*, *Rabi* and *Zaid* seasons. The *kharif* season starts from mid-July and goes up to end of November. The research focused on study of *kharif* season yield with weather variables. The duration of yield data considered was 1993 (this year 13 districts are partitioned into 30 districts) to 2018 (data are available till this year) for k*harif* season. The weather data like precipitation, maximum temperature, minimum temperature and relative humidity were collected from NASA power website on daily basis for the said period then averaged on weekly basis. The weeks considered were pre-sowing to till harvesting which was 23rd standard meteorology week to 41st standard meteorological week.

2.2 Analytical Procedure

2.2.1 Construction of weather indices

Throughout the cropping season, instead of considering simple average of weather parameters, the weekly weather data must be transformed into a single representative value that takes into consideration the weekly impact of weather on crop yield in order to comprehend the crop-weather relationship. The method used to calculate this representative value, known as the weather index, is described below.

In every given agricultural season, let m represent the number of weeks, and k represent the quantity of meteorological variables used in the research. Let the yield and yield loss due to pest be represented by Y_t and YL_t where t-year (t=1, 2…) and the value of the i^{th} weather variable in the w^{th} week by X_{iw} (i=1, 2…, k; w=1, 2…, m). It is necessary to examine each meteorological variable's contribution independently since they all have distinct effects on crop productivity. In addition, the impact of a given weather variable on agricultural productivity varies considerably from week to week.

Therefore, a weighted variable is created with regard to each weather variable for each year under consideration utilizing the weekly data of each weather variable. Simple correlation coefficients between the weekly weather data of the i^{th} weather variable collected throughout the years and the crop production (adjusted for time trend) are used to assign weights to the weekly data of that weather variable. The adjustment was carried out to remove long term trend effect from crop yield before analyzing its relationship with weather parameters. This adjustment was done to ensure that correlation between yield and weather variables is not confounded by unrelated long term changes in yield that could result from factors like technological improvements, release of new improved varieties etc. Specifically, the correlation between yield and m^{th} week data of a meteorological variable over time will be the weight assigned to that variable. We refer to these weighted variables as weather indices. When the weekly influence of a given weather variable is combined in the following way, the weather indices of that weather variable for that year are indicative of the weather variable value for that year.

$$I_{t(i)} = \sum_{w=1}^{m} r_{[Y_t, X_{tw(i)}]} X_{tw(i)} / \sum_{w=1}^{m} r_{[Y_t, X_{tw(i)}]}, \qquad (2.1)$$

Where,

$I_{t(i)}$ = weather index for i^{th} variable in year t

Y_t = detrended yield of rice in year

$X_{tw(i)}$ = weekly value of i^{th} variable in w week for year t.

$r_{[Y_t, X_{tw(i)}]}$ = correlation of week w data of i^{th} variable with detrended yield Y_t.

These weighted indices address the weekly distribution of weather variables in relation to rice yield and yield loss due to pest. They were employed as independent variables in a multiple linear regression model to illustrate the impact of weather variables on crop yield and yield loss serving as dependent variables.

2.2.2 Multiple Linear Regression

The technique through which the variation of dependent variable is explained through various independent variables are known as multiple linear regression. In the study of genetics, Sir Francis Galton was the first to present the regression theory (Galton, 1997) [6]. The establishment of linear relationship between rice yield and yield loss due to pest as dependent variable and the weather indices as independent variable, so that this can depict the contribution of weather parameters on the dependent variables separately. The regression equations are written as

$$Y_t = \alpha_1 + \sum_{i=1}^{k} \beta_{1i} I_{t(i)} + \varepsilon_1, \qquad (2.2)$$

Where,

Y_t = rice yield at time t

α_1 = intercept term

β = regression coefficient

$I_{t(i)}$ =weather index for i^{th} variable in year t
ε_1 = error term

The degree and direction of the correlation between meteorological factors and agricultural yield are shown by the coefficients β. A particularly helpful tool for researching how weather affects crop yield is the multiple linear regression model. Azfar *et al*. (2018) [4] used a variety of statistical models to anticipate the yield for Faizabad District and investigated the impact of weather variables on the yield of mustard and rapeseed at different phases of the crop. Wind power in Rajasthan was predicted using basic linear regression models and the least squares approach (Kumar *et al*., 2019) [5].

The relative significance of each meteorological variable and its contribution to the overall variation explained by the model were then determined by applying hierarchical partitioning to this regression model through Shapley R^2 partition.

3. Results and Discussions

3.1 Multiple linear regression of yield on weather variables

The regression of yield on average weather parameters has been computed and depicted in table

Parameters	Estimates	Standard error	P-Value	R^2	Adj. R^2	Shapley R^2 Contribution	Percentage of total R^2
Precipitation	0.080303	16.47224	0.996156	47.3796	37.3567	7.3619	15.53812
Maximum Temperature	1248.101	720.0923	0.097711			2.4935	5.262814
Minimum temperature	-1578.96**	537.5572	0.00787			19.2814	40.69557
Relative Humidity	412.9239**	157.54	0.015961			18.2428	38.50349

** significant at 1% level of significance.

This regression model has explained the total variation 47.38% of yield through weather parameters. In this result it has been found that the minimum temperature and relative humidity have been played a vital role in explaining the variation of yield. Both the parameters are highly significant and contributing 40.7% and 38.5% of total variation, respectively. The minimum temperature is affecting in negative direction whereas relative humidity is in positive direction. Precipitation and maximum temperature have non-significant effect on yield for Bargarh district.

3.1. Construction of weather indices.

The weather indices have been constructed as per the above mentioned procedures. The weekly weather data have been converted to yearly indexed data which has captured the crop stages in every phase. The index values are presented in below table.

Table 1: yield, detrended yield and weather indices from 1993-2018

Year	Yield	Detrended yield	$I_{prep.}$	I_{maxt}	I_{mint}	I_{rh}
1993	1705	143.88	60.74	28.84	20.79	81.29
1994	1703	131.24	51.15	28.39	20.66	83.71
1995	1675	92.60	57.30	28.42	20.55	81.78
1996	1130	-463.03	29.55	29.03	19.61	80.10
1997	1697	93.33	69.46	28.87	21.23	84.30
1998	1432	-182.31	45.86	29.13	22.54	84.75
1999	1854	229.05	55.99	28.39	20.30	82.49
2000	842	-793.59	9.06	31.96	20.44	70.68
2001	1728	81.77	25.75	28.93	21.08	83.85
2002	783	-873.87	34.78	29.88	20.66	74.45
2003	1895	227.49	53.82	28.59	21.16	83.90
2004	1520	-158.16	63.50	28.49	19.86	80.25
2005	1716	27.20	52.77	28.35	20.36	81.63
2006	1811	111.56	41.71	29.08	19.95	82.44
2007	2688	977.92	79.79	28.40	18.76	82.86
2008	1736	15.28	47.84	28.73	20.55	83.27
2009	1881	149.64	49.15	29.03	19.77	81.01
2010	1798	56.00	21.56	29.95	21.54	81.00
2011	2157	404.36	75.46	28.84	20.41	81.72
2012	2953	1189.72	81.96	28.34	18.61	84.28
2013	1705	-68.92	58.87	28.54	20.76	82.40
2014	2578	793.44	43.05	28.81	20.09	79.78
2015	1243	-552.20	35.58	29.58	20.46	80.60
2016	1883	77.16	65.53	28.80	19.24	82.31
2017	446	-1370.48	19.02	29.19	21.68	80.48
2018	1488	-339.12	30.75	29.62	20.29	79.18

The indices have been constructed on detrended yield and their representation would be annual. Figure 1 and 2 reflected the trend of yield and detrend yield respectively.

The variation of rice yield of Bargarh district due to weather parameter indices can be seen through a multiple linear regression of rice yield on weather indices. The details are presented in Table 2.

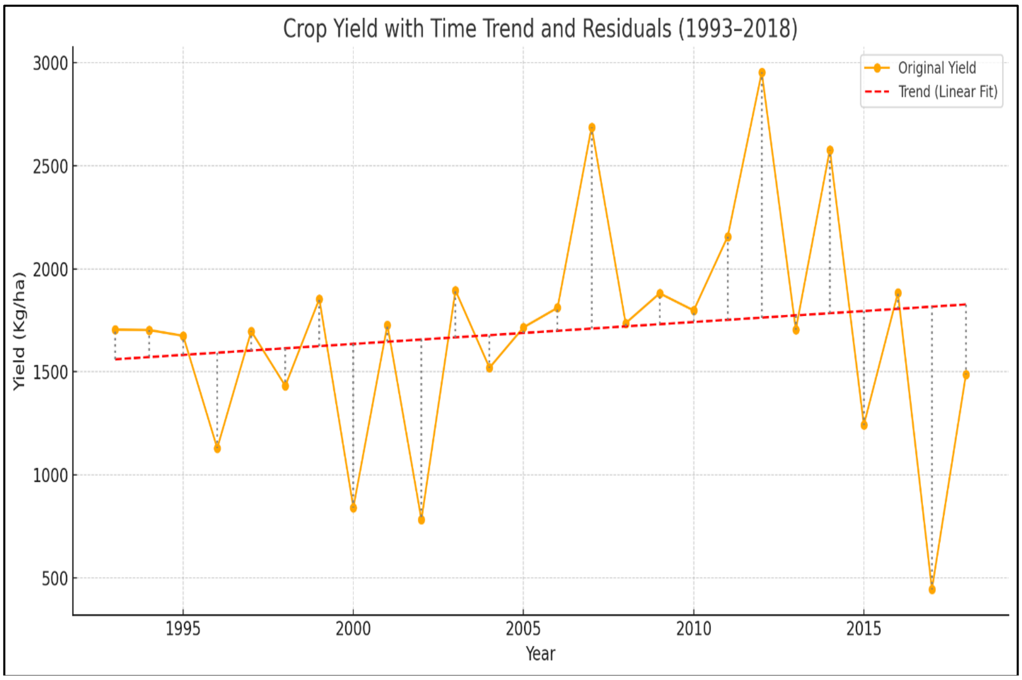

Fig 1: Yield of rice with trend over the years

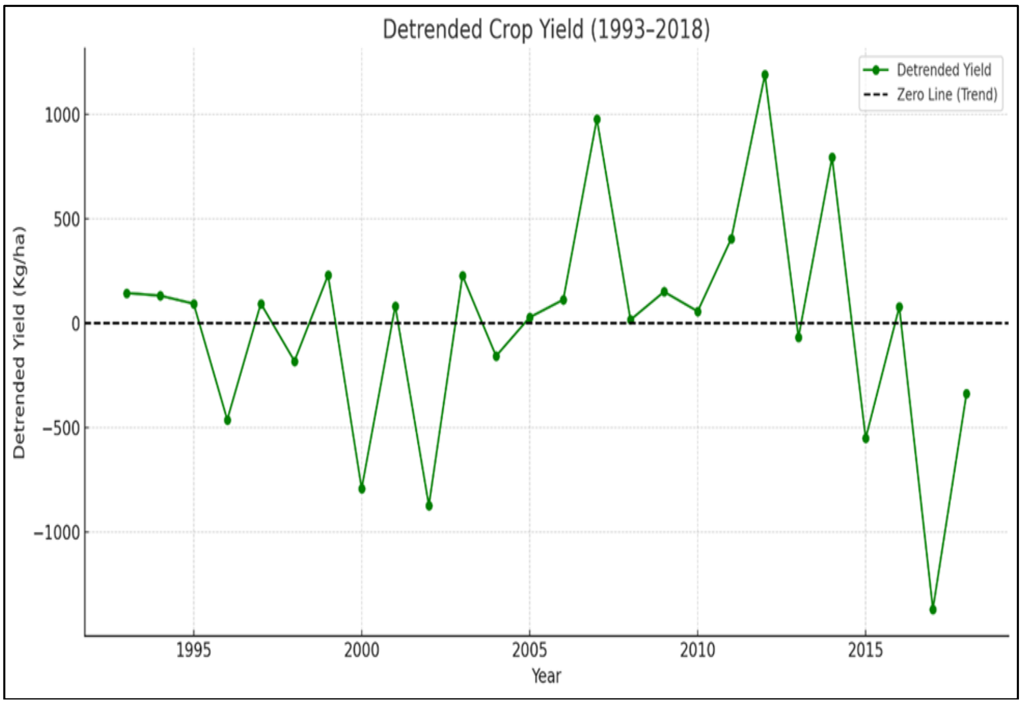

Fig 2: Detrended yield of rice

Table 2: Parameter estimates of multiple linear regression and the coefficients showing the Impact of weather variables on rice yield

Parameters	Estimates	Standard error	P-Value	R^2	Adj. R^2	Shapley R^2 Contribution	Percentage of total R^2
I_{prep}	9.358575	5.592333	0.108397	66.37218	64.1993	10.15149	15.2948
I_{maxt}	41.32158	57.47171	0.479715			1.873882	2.823294
I_{mint}	-280.758**	102.4073	0.011911			27.24581	41.05005
I_{rh}	71.07445**	25.99376	0.012108			27.10099	40.83186

** significant at 1% Level of significance.

From the above table, it can be seen that 66.37% variation of yield has been explained through weather variables. The minimum temperature index alone has explained around 41.05% of the total variation which is also statistically significant, suggesting that it is a potential influencer. Relative humidity has highly significant positive impact, which has explained 40.83% of the total variation. Precipitation and maximum temperature have no significant effect. The model with intercept came out with negative coefficients with high standard error. Hence, the model without intercept has been considered.

4. Conclusion

The demand of food grains especially the staple food rice with rising population is surging day by day. As the cropping area declines with time due to urbanization. So, production demand could be supplemented by declining the abiotic and biotic stress on plants. The abiotic stress like precipitation, maximum temperature, minimum temperature and relative humidity impact on rice yield will picturize to adopt new packages and practices. Bargarh district is called as rice bowl of Odisha which grows rice three times in a year. The influence of weather on Bargarh rice yield has been studied through multiple linear regression where the regression model of yield on weather parameters have explained 47.38% of total variation of yield whereas the regression of yield on weather indices have explained 66.37% of total variation of yield. In first situation, only the average values of weather parameters of *kharif* period have been considered but in second situation, weather indices which are constructed on weekly relationship of weather with yield. In second situation as it has been considered the effect of weather variables on yield during the cropping period instead of normal average, it has explained the variation of yield in better way than the normal average weather variable. In both the cases, minimum temperature has been highly influential and negatively affecting the rice yield. Relative humidity has been crucial for rice production in Bargarh district influencing in positive direction.

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