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MULTI-FACTORAL OLSR AND MLR MODELLING OF CLIMATOLOGICAL AND CROP PRODUCTION TRENDS IN COASTAL AREAS OF PAKISTAN

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Abstract

Facing the impacts of climate change and decline in the agriculture crop productions, the coastal districts of Southern Pakistan, Thatta and Badin, are facing severe economic instability due to their high dependency on climate sensitive natural sources for livelihood. These issues need to be resolved by taking appropriate measure with respect to climate change mitigation and adaptation mechanisms based on trend analysis of climatological variables and future forecasting approaches. Since agriculture is the primary livelihood option of these districts, climatological variations have highly altered sowing and harvesting periods of agricultural crops. In this study climatological variable including maximum temperature, minimum temperature, precipitation, wind speed and relative humidity were statistically analyzed and their impacts on the yield of wheat, rice and sugarcane crops in Thatta and Badin were computed for a period from 1981 to 2019 (39 years).

Using multi-factoral approach and applications of Pearson's Correlation, Ordinary Least Square Regression (OLSR) and Multiple Linear Regression (MLR) Models, 30 OLSR-based and 6 MLR-based statistical equations were developed for future forecasting and prediction of the climatological impacts. Temperature and precipitation have shown highly significant correlation and regression estimates; whereas wind speed and relative humidity have lesser impacts on crop production. The study provides baseline for forecasting future trends in the crop yield with regards to climatological variations in the study area.

Key words: Correlation; Regression; Climate; Agriculture; Crop production; Temperature; Precipitation.

Introduction

Climate change, has a far-reaching global implication (Anon., 2014) that extensively altered various ecosystems of the Earth (Thayer *et al.*, 2020). In developing countries, the impacts of climate change are more severe and alarming (Carattini *et al.*, 2020). Being a South Asian country, Pakistan is highly vulnerable to climate change (Ahmed *et al.*, 2019) and ranked 5th in terms of Climate Vulnerability Index (Eckstein *et al.*, 2019). Despite this, the economy of Pakistan is largely dependent on agriculture and contributes to about 18.5% to the country's Gross Domestic product (GDP) (Anon., 2019) whereas, 43% of labors are engaged in agriculture as their prime occupation (Ali & Erenstein, 2017). A significant decline in the crop cultivation area and yield in the country has been observed over the last few decades due to climate change (Ahmed & Schmitz, 2011).

The major climate impacts are alteration in temperature, changes in the precipitation, wind speed, relative humidity and sunshine hours that are widely studied in Pakistan (Janjua *et al.*, 2010; Rahman *et al.*, 2017; Ali *et al.*, 2017; Magsi *et al.*, 2018) in South Asia (Kaur *et al.*, 2017; Tesfaye, *et al.*, 2017) and at global scale (Basche *et al.*, 2016; Mendelson & Wang, 2017; Huong *et al.*, 2019). The impacts of the climatological variation on agricultural crops production particularly in developing countries become more intense due to additional factors such as weak economic stability (Mirza, 2011), poverty, climate-sensitive sources of incomes (World Bank, 2009), lack of natural resources including water (Mahmood *et al.*, 2016), and less coping capacity against disasters (Mirza *et al.*, 2019) such as floods (van der Schrier *et al.*, 2018; Mahessar *et al.*, 2019) and droughts (Ahmed *et al.*, 2018; Siddiqui & Safi, 2019; Solomon, 2019).

In Sindh, the cultivation area of crops is lesser as compared to the province of Punjab however, the crops yield per hectare is greater than other provinces (Ahmed & Schmitz, 2011). The major cash crops of Sindh particularly Thatta and Badin are wheat, rice and sugarcane. Wheat (*Triticum aestivum*), is an important food and cash crop all over the country and the cultivation of wheat is extensively done in Thatta and Badin. It accounts for 1.6% to the country's GDP and 8.9% to the value addition of agriculture sector. During 2017-18 and 2018-19, the production of wheat in Pakistan has increased by 0.5 % from 25,076 thousand tons to 25,195 thousand tons (Anon., 2019). Rice (*Oryza sativa)*, the major water demanding crop, is also an important food and cash crop in Pakistan and accounts for 0.6% to the country's GDP and 3% to the value addition of agriculture sector. During 2017-18 and 2018-19, the production of rice in Pakistan has reduced by 3.1% from 7,450 thousand tons to 7,202 thousand tons (Anon., 2019). Sugarcane (*Saccharum officinarum*), is also a vitally important cash crop in Pakistan and luxuriously grown in Thatta and Badin. It accounts for 0.5% to the country's GDP and 2.9% to the value addition of agriculture sector. During 2017-18 and 2018-19, the production of sugarcane in Pakistan has reduced by 19.4% from 83,333 thousand tons to 67,174 thousand tons (Anon., 2019).

Therefore, this study is designed to focus essentially on multi-factoral statistical modeling of the climatological and agricultural crop production over a longer time series in the districts of Thatta and Badin. Pearson's correlation was employed and two types of regression models including Ordinary Least Square Regression (OLSR) Model and Multiple Linear Regression (MLR) Model were developed with respect to climatological variables and crop yield of wheat, rice and sugarcane. These models have computed separate as well as combine impacts of each climatological varaible on the selected agricultural crop's production during 1981-2019 (39 years) by developing statistical equations.

Material and Methods

Study area: Thatta (24°44'50" N and 68°04'19" E) and Badin (24°39'20"N and 68°50'14" E), the two coastal districts of Sindh are highly prone to climate change. Climate change implications on natural resource are causing alteration and damage to agricultural crops (Ahmed *et al.*, 2016; Arshad *et al.*, 2016). District Thatta, including Sujawal, comprises an area of 17355 km^2 and 9 sub-districts (Ghorabari, Jati, Keti Bunder, Kharochan, Sujawal, Mirpur Bathoro, Mirpur Sakro, Shah Bunder and Thatta) and district Badin comprises a geographical area of 6726 km^2 and 5 sub-districts (Badin, Golarchi, Matli, Talhar and Tando Bago). According to the 2017 Census of Pakistan, population of Thatta and Badin was 1,761,784 and 1,804,516, respectively (Anon., 2017). Climate of Thatta can be characterized as arid to semi-arid and while Badin has moist and humid climate. Mean maximum temperature in Thatta and Badin is 32°C and 34°C and minimum temperature is generally 21.7°C. Mean annual precipitation generally varies from 169 mm to 183 mm in the two coastal districts.

Data sources: Following the definition and standards of Intergovernmental Panel on Climate change (Anon., 2014) and World Meteorological organization (Anon., 2017) for the analysis of climate change trends, this study employed to investigate the statistical significance of climate change impacts on agricultural production over 39 years (1981-2019). This study is based on the long term 4-decadal analysis of climatological (maximum temperature, minimum temperature, precipitation, wind speed and relative humidity) and crops production data (wheat, rice and sugarcane). Climatological data was taken from the Pakistan Meteorological Department (PMD) stations located in Karachi and Badin, since there is no station in Thatta. Whereas, agricultural crops production data was acquired from Pakistan Bureau of Statistics (Anon., 2019) through http://www.amis.pk/ which is available at district level.

Trend estimation: Meteorological and agricultural crop productivity trend analysis was done using graphical method on annual basis (Rathnayake, 2019) over 1981 to 2019 in order to verify the impacts of maximum temperature, minimum temperature, precipitation, wind speed and relative humidity on agricultural cash crops including wheat, rice and sugarcane in Thatta and Badin. During trend estimation, each climatological variable was analyzed by the plotting against the respective agricultural crop. Due to variation in the units and weights of each climatological variable and agricultural crops, primary and secondary vertical axis were used for the plotting the trend analysis from 1981 to 2019.

Data normalization and assumptions validation: For statistical analysis, normalization of the data set was done using standard deviation (σ), skewness and kurtosis for each variable over 1981 to 2019 as shown in Equations below (Ghani & Ahmed, 2010; Panda & Sahu, 2019; Sharma & Ojha, 2020):

$$\sigma = \frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^2$$

$$Skew = \frac{N}{(N-1)(N-2)}\sum_{i=1}^{N}\left(\frac{x_i-\mu}{\sigma}\right)^3$$

$$Kurt = \frac{N(N+1)}{(N-1)(N-2)(N-3)}\sum_{i=1}^{N}\left(\frac{x_i-\mu}{\sigma}\right)^4 - \frac{3(N-1)^2}{(N-2)(N-3)}$$

where,
σ = Standard deviation
N= number of years
x_i, i = 1, 2 . . . N is the consecutive years
μ = mean of observations

Correlation analysis: Pearson correlation model, also known as zero-order correlation, was applied on the climatological and agricultural crops production data to check the relationship between the dependent and independent variables over decades (Ruigar & Golian, 2015). The resulting value of person correlation varies from -1 to +1. The positive and negative values of the correlation coefficient determine that the relationship trend between the two variables is directly (if positive) or inversely (if negative) related at the defined confidence interval. In this study, the results were analyzed at confidence intervals 95% (α = 0.05) and 99% (α = 0.01) using significance levels (probability or p-values) $p<0.05$ and $p<0.01$, respectively. The calculation of person's correlation is based on the following model:

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{[n\sum x_i^2 - (\sum x_i)^2][n\sum y_i^2 - (\sum y_i)^2\ ]}}$$

where,
r_{xy} = Pearson r correlation coefficient between x and y
n = number of years
x_i = value of x (for ith year
y_i = value of y (for ith year)

Regression analysis: Two types of statistical models are being employed in this study including Ordinary Least Square Regression (OLSR) Model and Multiple Linear Regression (MLR) Model for distinct and combine impacts of each climatological variable on crop production, respectively.

Ordinary least square regression (OLSR) model: For linear regression model, the impact of each climatological variable was separately found against individual cash crops production of Thatta and Badin using the following equations. By developing these equations, *Analysis ToolPak* Add-ins in Data Analysis tool (Warner & Meehan, 2001; Lambert *et al.*, 2011) of MS Excel v2016 was used to conduct the Ordinary Least Square Regression (OLSR) (Hussain & Mudasser, 2007; Ali *et al.*, 2017; Magsi *et al.*, 2018) in the form of r-squared values (R^2) for the trend of climatological variable in contradiction of crop production. The value of R^2 was used to determine the percent contribution of each climatological variable to the agricultural crop production.

$$CP_{it} = \beta_0 + \beta_1\, Tmax_{it}$$
$$CP_{it} = \beta_0 + \beta_1\, Tmin_{it}$$
$$CP_{it} = \beta_0 + \beta_1\, P_{it}$$
$$CP_{it} = \beta_0 + \beta_1\, WS_{it}$$
$$CP_{it} = \beta_0 + \beta_1\, RH_{it}$$

where,
CP_{it} = production of i^{th} crop in t^{th} year
β_0 = coefficient to be calculated for constant
β_1= coefficient to be calculated for slope
$Tmax_{it}$ = mean annual maximum temperature for i^{th} crop in t^{th} year
$Tmin_{it}$ = mean annual minimum temperature for i^{th} crop in t^{th} year
P_{it} = mean annual precipitation for i^{th} crop in t^{th} year
WS_{it} = mean annual wind speed for i^{th} crop in t^{th} year
RH_{it} = mean annual relative humidity for i^{th} crop in t^{th} year

Multiple linear regression (MLR) model: Multiple Linear Regression (MLR) Model is basically incorporated in the trend analysis studies to study the linear relationship between the response (dependent) and explanatory (independent) variables. It is the extension of the OLSR Model. MLR analyses of the climatological trends of Badin and Thatta that were observed for their impacts on the production of wheat, rice and sugarcane in the respective districts on IBM SPSS Statistics 22. Multiple regression models were developed to assess the extent of the variation in the production of crops (dependent variable) due to climatological changes (independent variables) and their statistical significance (Mahmood *et al.*, 2012; Ali *et al.*, 2017; Rahman *et al.*, 2017; Magsi *et al.*, 2018).

$$CP_{it} = \beta_0 + \beta_1\, Tmax_{it} + \beta_2\, Tmin_{it} + \beta_3\, P_{it} + \beta_4\, WS_{it} + \beta_5\, RH_{it+\epsilon}$$

where,
$\beta_0 + \beta_1 + \beta_2 \ldots\ \beta_n$ = coefficient to be calculated for each climatological variable
ϵ = Error Term

Results and Discussion

Statistical analyses of climatological and agricultural production variables were computed from 1981-2019 of recorded data in Thatta and Badin. For each statistical analysis all climatological variables including maximum temperature (Tmax), minimum temperature (Tmin), precipitation (P), wind speed (WS) and Relative humidity (RH) were considered as explanatory (independent) and agricultural production as response (dependent) variable. All the data used in the statistical analysis is the mean on annual basis.

Descriptive statistics and data validation: The descriptive statistics from 1981-2019 of the climatological and agricultural production variables in Thatta and Badin is shown in Table 1. It is represented for minimum, maximum, mean, standard deviation (SD), skewness and kurtosis that were done for the normalization of the data over the defined period of time. Generally, skewness for a normally distributed data is usually resulted as zero; however, the minimum and maximum range of skewness in Badin and Thatta for climatological and agricultural production variables were 0.00 to 1.27 and 0.29 to1.26, respectively. Among both types of variables, all the values for skewness are positive (skewness ≥ 0) which shows that all of the data observations are distributed on the right side of the probability distribution (Sharma & Ojha, 2020). During 1989 to 2015, relatively higher values of skewness were observed for the wheat, rice and sugarcane production with regards to temperature, precipitation and humidity in Pakistan (Ali *et al.*, 2017). Similarly, for kurtosis, the relative tailedness of the data observations on probability distribution than normal distribution, a normally distributed data is usually resulted as zero. The minimum and maximum range of kurtosis in Badin and Thatta for climatological and agricultural production variables is -1.36 to 1.14 and -1.16 to 6.55, respectively. However, the resulting values less than zero (kurtosis ≤ 0) for the kurtosis shows that the values are platykurtic and less extreme values persists in the data. In contrast the resulting values more than zero (kurtosis ≥ 0) shows that the values are leptokurtic and more outliers are existing in the observations than the normal data (Wiśniewski *et al.*, 2017). The precipitation trends in Thatta (1.14) and Badin (6.55) shows leptokurtic kurtosis. Kurtosis for precipitation was also recorded as higher than other variables during 1989 to 2015 at national level (Ali *et al.*, 2017). Thus, the descriptive statistics shows that the data is suitable to compute the further statistical tests and analysis.

Climatological and crop production trends: Consequent to the inference of descriptive statistics, trends were also analyzed over 39 years of time period (1981-2019) in order to observe the annual increasing or decreasing trend of the crop production due to the five climatological parameters. In Thatta, the trend of maximum and minimum temperature, precipitation, wind speed and relative humidity and their impacts on production of wheat crop shows that despite increase in temperature, production of wheat crop also increased. In contrast, decrease in precipitation and relative humidity is favorable for the production of wheat crop in Badin (Fig. 1). For rice, the trend shows that decrease in precipitation and relative humidity during 2009-2010 suddenly reduced the rice production (Fig. 2). With the decrease in precipitation in Badin, sugarcane production also declined in 2009-2010, but 2011 and onwards, decrease in precipitation favors the increase in sugarcane production (Fig. 3). In Badin, the trends of the relation between climatological parameters and agricultural crops production are almost similar as that of in Thatta (Figs. 4-6).

Table 1. Descriptive statistics.

	Descriptive Statistics						
	Thatta						
	N	Min	Max	Mean	SD	Skewness	Kurtosis
CP_W	39	5.30	56.70	25.05	18.96	0.58	-1.36
CP_R	39	32.70	250.50	130.72	69.54	0.21	-1.24
CP_S	39	432.20	2621.10	1347.90	602.94	0.29	-0.97
Tmax	39	31.30	34.90	32.64	0.94	1.08	0.19
Tmin	39	19.60	28.00	22.70	2.86	0.90	-0.81
P	39	0.00	481.50	121.99	127.49	1.27	1.14
WS	39	5.70	9.10	7.48	0.83	0.00	-0.05
RH	39	45.50	53.80	48.96	2.48	0.41	-0.82
	Badin						
	N	Min	Max	Mean	SD	Skewness	Kurtosis
CP_W	39	24.60	117.00	67.32	27.74	0.40	-1.16
CP_R	39	25.10	543.00	196.99	150.75	1.26	0.43
CP_S	39	1128.20	4090.90	2555.17	706.04	0.29	-0.48
Tmax	39	32.30	37.50	33.98	1.59	1.07	-0.14
Tmin	39	19.30	27.80	22.11	2.98	1.02	-0.80
P	39	0.00	913.90	166.09	179.77	2.04	6.55
WS	39	5.20	9.40	6.77	1.09	1.07	0.27
RH	39	36.20	44.30	40.69	2.01	0.07	-0.61

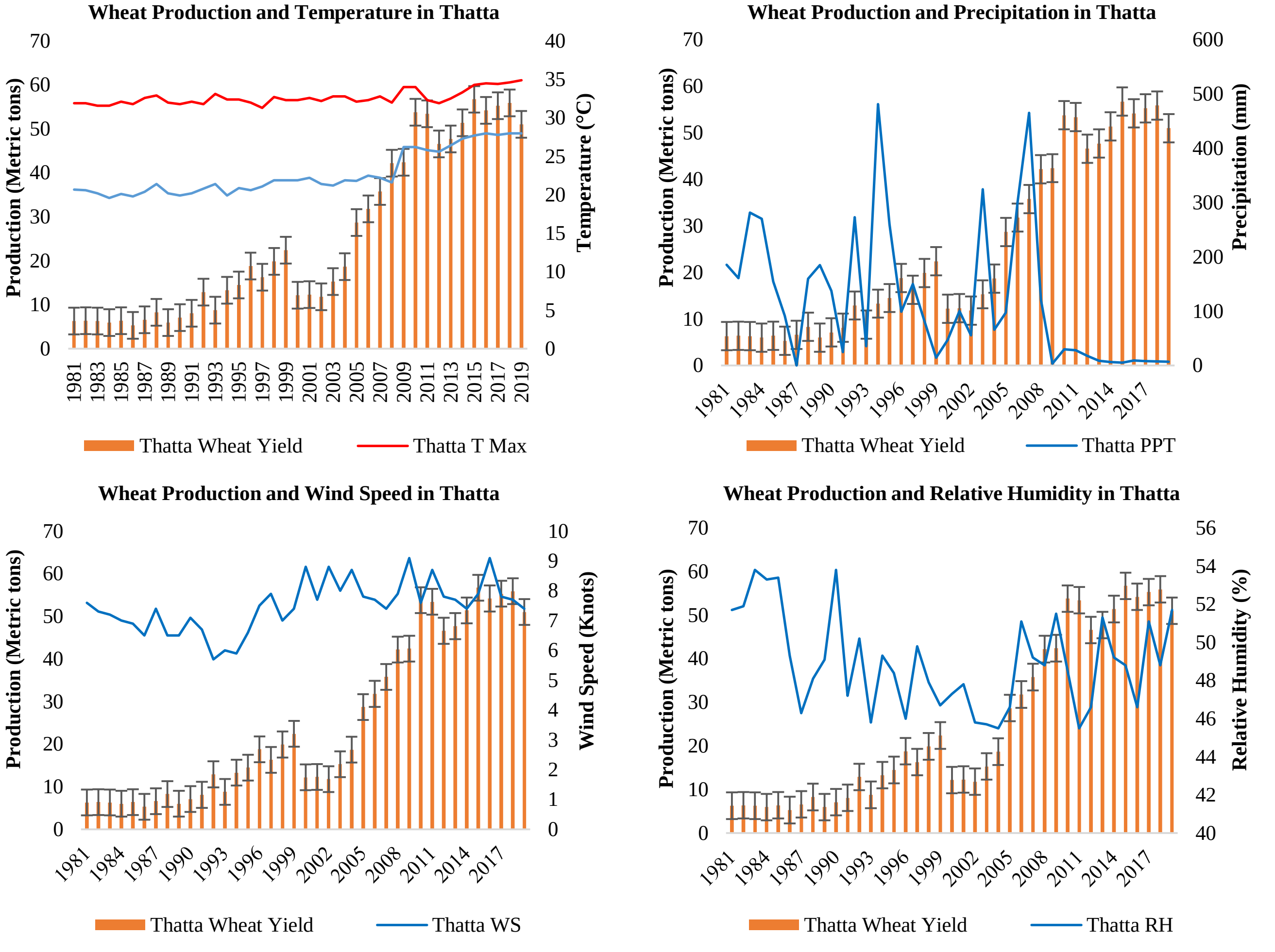

Fig. 1. Wheat production and climate in Thatta.

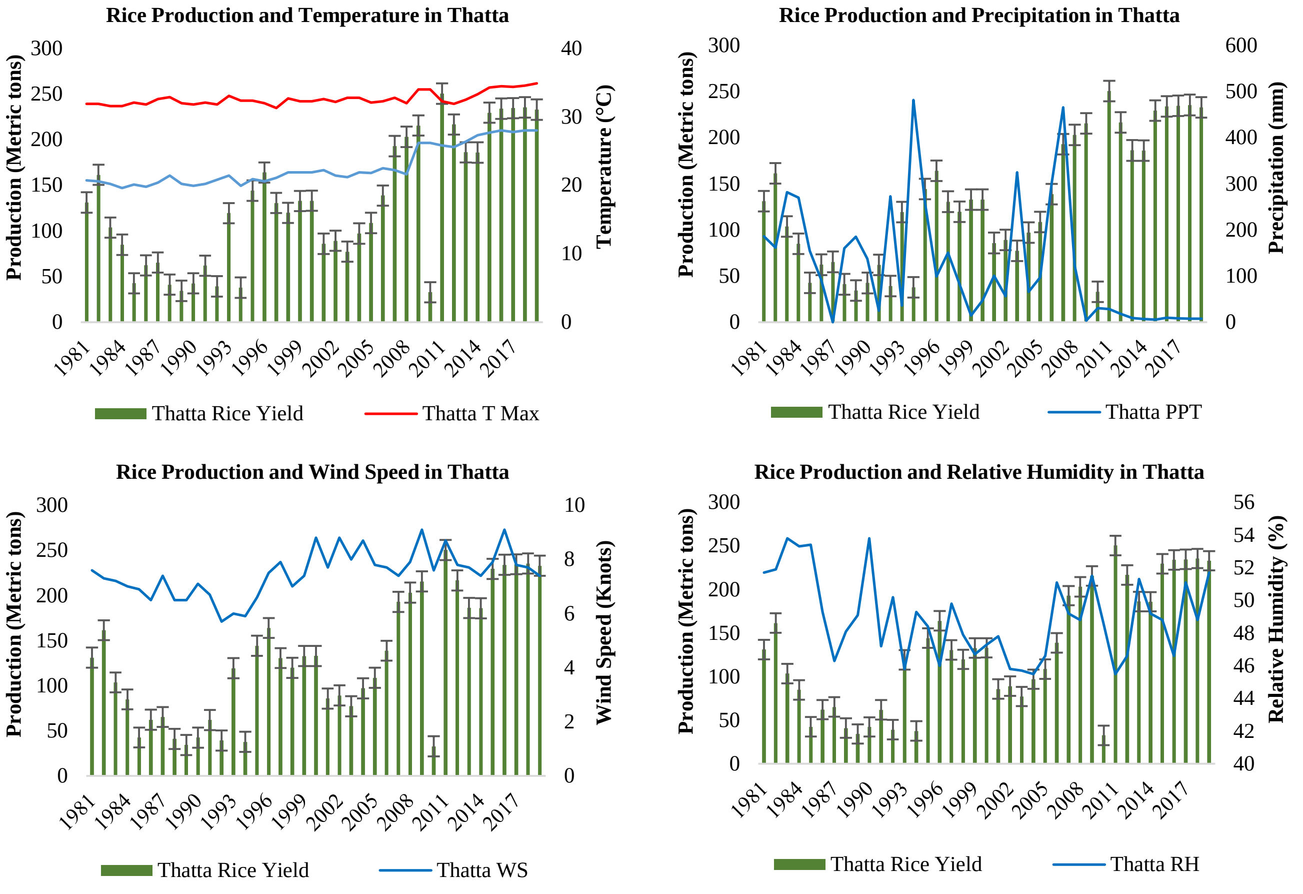

Fig. 2. Rice production and climate in Thatta.

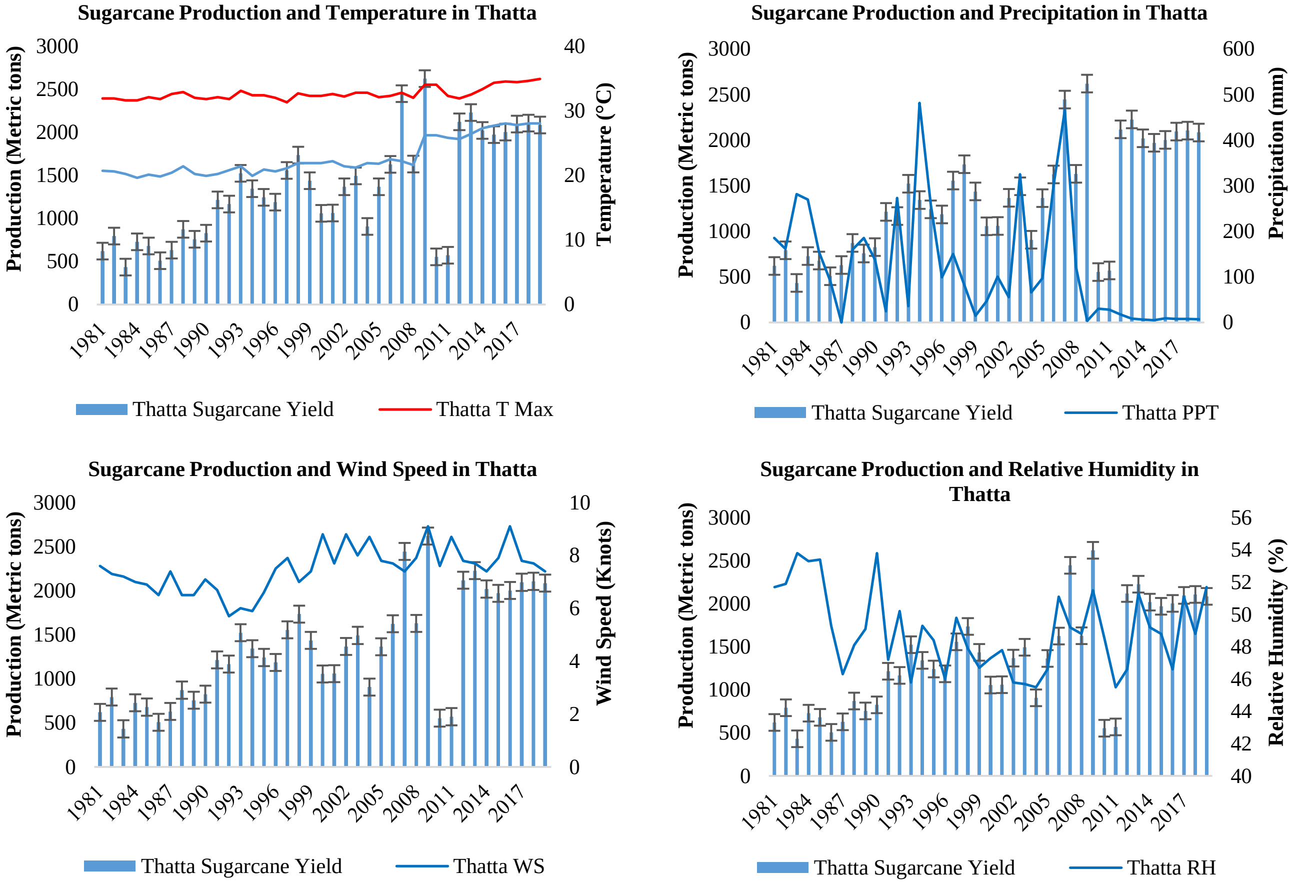

Fig. 3. Sugarcane production and climate in Thatta.

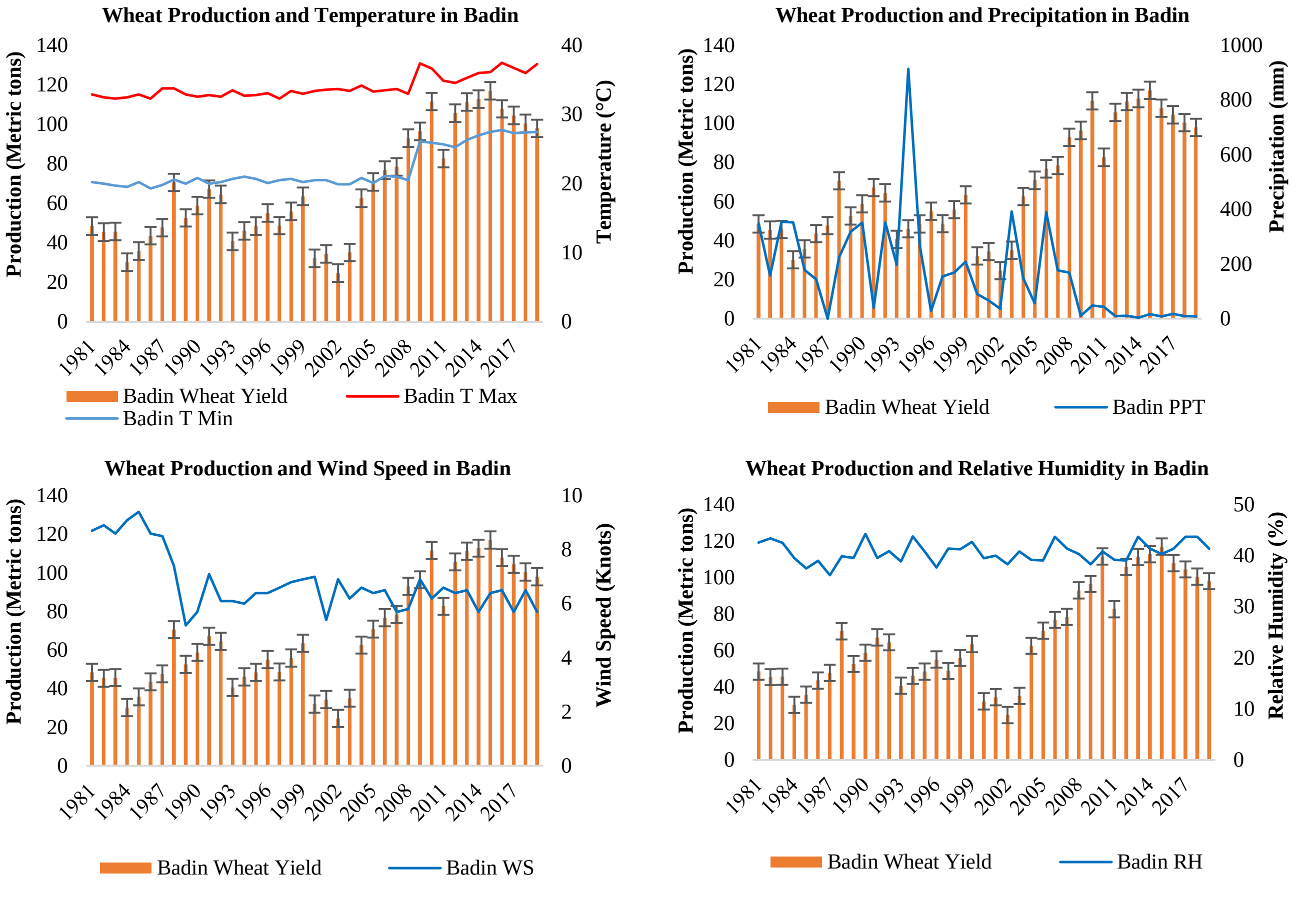

Fig. 4. Wheat production and climate in Badin.

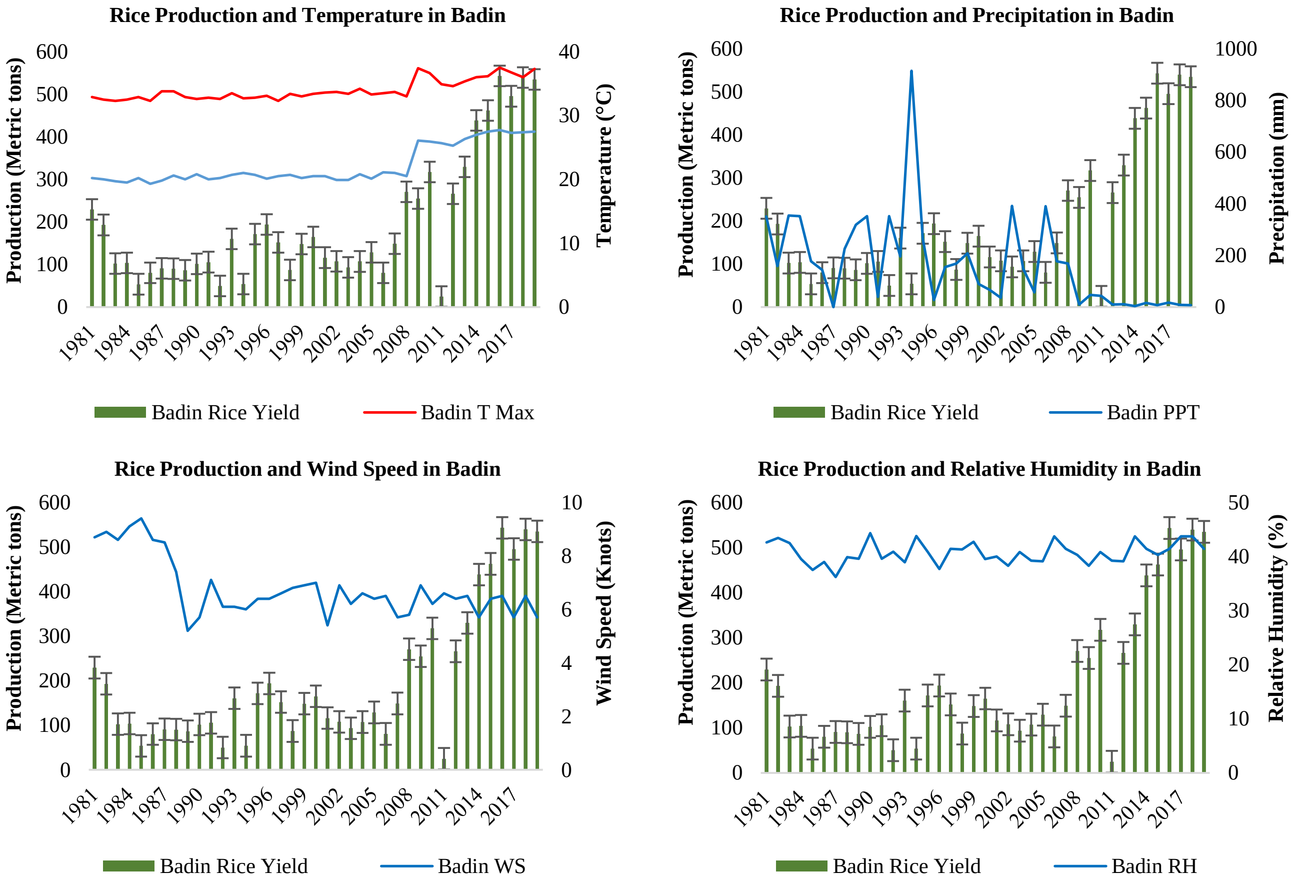

Fig. 5. Rice production and climate in Badin.

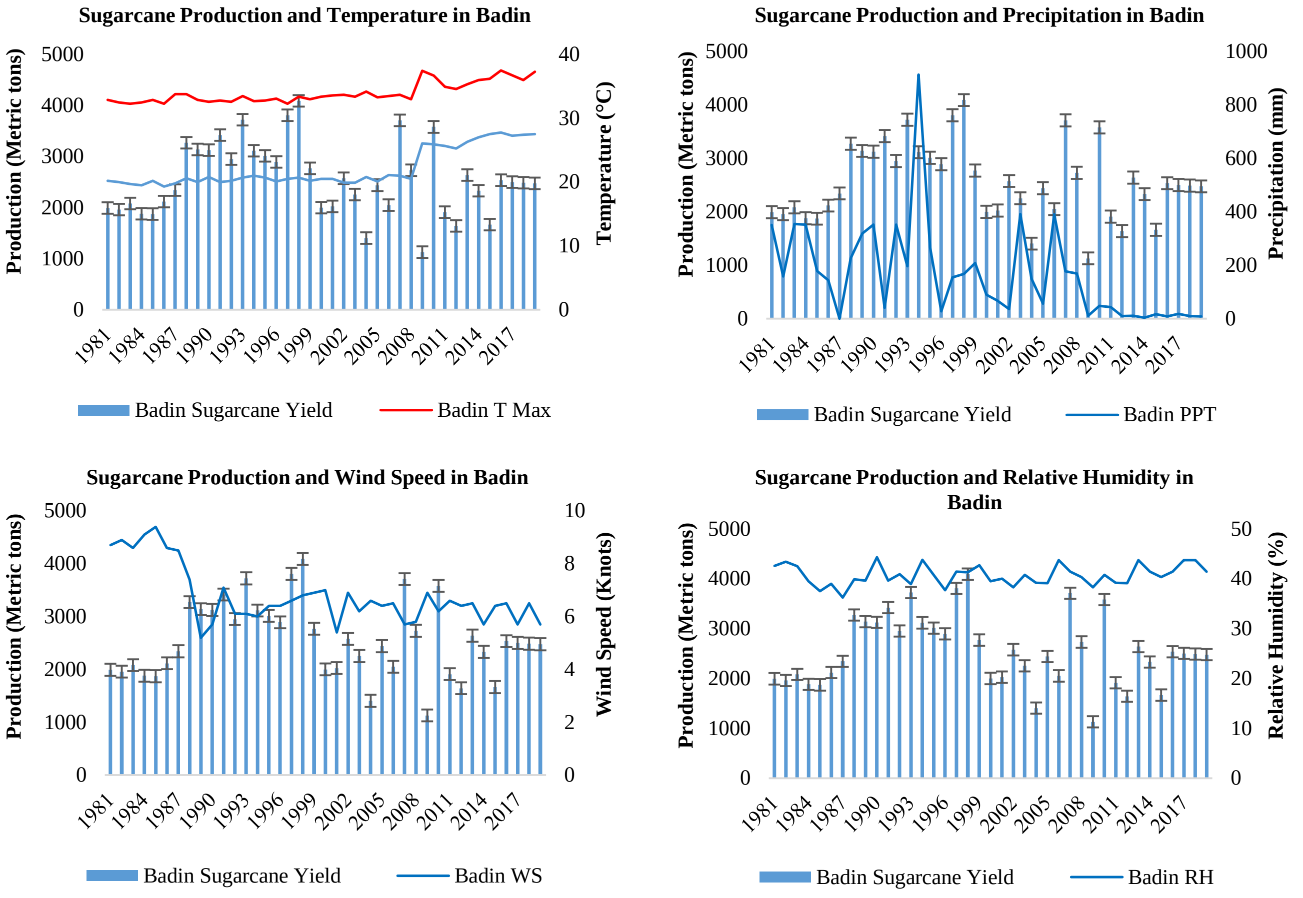

Fig. 6. Sugarcane production and climate in Badin.

Pearson's correlation between climate and crop production: The Pearson's correlation between crops production and climatological variables is shown in Table 2. In Thatta, the impacts of maximum temperature, minimum temperature and wind speed are significantly positive, except wind speed, favorable for the increasing production of wheat, rice and sugarcane. In contrast, the impacts of precipitation are significantly negative for the production of wheat and rice. Negative impacts of precipitation are also found for the growth of sugarcane in Thatta, but insignificant correlation is observed. The impacts of relative humidity on all three crops are negative but insignificant.

Dissimilar trends of the correlation between climatological and crops production variables were observed in Badin in comparison with the Thatta district. Maximum and minimum temperature and precipitation have significantly positive impacts on the growth of wheat and rice; however, insignificant and negative correlation was observed for the production of sugarcane crop. Precipitation has significant negative impact on the production of wheat and rice and insignificant positive impact on sugarcane. The correlation between relative humidity and each crop's production is significant and positive.

OLSR and MLR modeling: OLSR Model was used to compute the linear regression between the individual climatological variable on the production of each crop along with individual R^2 values for each trend. The output of this process is in the form of statistical graphs representing the linear positive or negative trend which (Figs. 7 and 8), statistical models (Table 3) and R^2 statistics (Table 4 and Fig. 9). MLR is the extension of the OLSR and was also computed to analyze the combine influence of all climatological variables on the production each type of crop along with single R^2 value for each model. The output of this process is in the form of statistical models with MLR coefficients (Table 5) and R^2 statistics (Table 6). The results of both the models strongly supports the trends estimated for each of the climate parameter and crops production.

The following models as an output of MLR Modelling of Climatological and Crop Production variables comprehensively explains that crop production which can be calculated or forecasted using the equations reproduced below for Thatta and Badin.

Impact of temperature on crop production: Linear positive regression has been observed between maximum and minimum temperature and production of wheat, rice and sugarcane crop in Thatta during 1981-2019. However, similar trends for only wheat and rice production were observed in Badin. The production of sugarcane crop and the maximum and minimum temperature shows linear negative regression in Badin.

Wheat crop is highly prone to temperature and precipitation variations. For sowing of wheat, low temperatures are favorable and the seed growth may be delayed if the temperature increases. In Pakistan, generally a significant and negative influence of temperature on wheat crop has been observed due to temperature abnormalities as shown by Heteroscedasticity and Autocorrelation (HAC) model during 1989 to 2015 (Ali *et al.*, 2017). However, using Vector Autoregression (VAR) for assessing the impacts of climate change on wheat crop, a study revealed that there is no significant negative trend of the impact of climate change on wheat crop over a period of 50 years (Janjua *et al.*, 2010). Using Multivariate Linear Regression analysis, another study reported that rise in temperature has positive impacts on production of rice crop in Larkana and Jacobabad (Rahman *et al.*, 2017). In Sindh province, per degree rise in maximum temperature may lead to decline of 378.764 thousand tons of wheat production while increase up to 149.469 thousand tons and 3493.398 thousand tons in rice and sugarcane production, respectively. In contrast to it, per degree rise in minimum temperature may cause increase of 1323.805 hundred tons and 25.455 thousand tons in the production of wheat and rice, respectively (Magsi *et al.*, 2018). These results were however, consistent with the present findings. Zia (2011) opined that 1ºC rise in temperature in the country corresponds to 6-9% decline in wheat production, that supports the present findings. Shakoor, *et al.*, (2011) suggested that positive impact of rainfall is less significant as compared to negative impact of temperature.

The resulting R-square (R^2) value OLSR Model shows that temperature is the highly influencing climatological variable for the production of crops. It was observed that, both the extremes of temperature, maximum and minimum, have varying value of R^2 when computed for regression against the crop production in both the districts. The minimum temperature has the highest impact on the production of wheat (R^2=0.8763, 87.63%) in Thatta as compared to wheat production (R^2=0.7524, 75.24%) in Badin. Following the minimum temperature, maximum temperature was the second highest influencing climatological variable on wheat crop. However, maximum temperature has the highest impact on the production of wheat (R^2=0.6276, 62.76%) in Badin as compared to wheat (R^2=0.497, 49.7%) in Thatta. Following by wheat, rice is also affecting by maximum and minimum temperatures. Rice crop in Badin has high influence of both maximum (R^2=0.6442, 64.42%) and (R^2 =0.7066, 70.66%) minimum temperatures as compared the rice crop in Thatta.

Impact of precipitation on crop production: Linear negative regression was observed for precipitation with all three crops in Thatta. In Badin, it was similar for wheat and rice crop. Only precipitation shows linear positive regression with sugarcane in Badin. A study based on national level analysis of precipitation and wheat, rice and sugarcane production showed insignificant and negative influence of precipitation on wheat and rice; however, significant and negative impact on sugarcane (Ali *et al.*, 2017) that corroborates the present findings.

Table 2. Pearson's correlation.

District	CP_{it}	r_{xy}	Climatological variables				
			Tmax	Tmin	P	WS	RH
Thatta	CP_W	r_{xy}	0.705**	0.936**	-0.420**	0.475**	-0.094
		Sig.	0.000	0.000	0.008	0.002	0.568
	CP_R	r_{xy}	0.500**	0.747**	-0.376*	0.542**	-0.057
		Sig.	0.001	0.000	0.018	0.000	0.729
	CP_S	r_{xy}	0.550**	0.643**	-0.170	0.290	-0.063
		Sig.	0.000	0.000	0.300	0.073	0.701
Badin	CP_W	r_{xy}	0.793**	0.867**	-0.459**	-0.422**	0.264
		Sig.	0.000	0.000	0.003	0.007	0.104
	CP_R	r_{xy}	0.804**	0.840**	-0.501**	-0.289	0.305
		Sig.	0.000	0.000	0.001	0.074	0.059
	CP_S	r_{xy}	-0.224	-0.203	0.175	-0.353*	0.187
		Sig.	0.171	0.215	0.286	0.027	0.254

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

Table 3. Ordinary least square regression (OLSR) models.

		Wheat	Rice	Sugarcane
Thatta	Tmax	$CP_W = -440 + 14.26\,T_{max}$	$CP_R = -1080.76 + 37.11\,T_{max}$	$CP_S = -10209.82 + 354.11\,T_{max}$
	Tmin	$CP_W = -115.58 + 6.19\,T_{min}$	$CP_R = -280.8 + 18.1\,T_{min}$	$CP_S = -1726.05 + 135.4\,T_{min}$
	P	$CP_W = 32.66 - 0.06\,P$	$CP_R = 155.7 - 0.2\,P$	$CP_S = 1446.2 - 0.8\,P$
	WS	$CP_W = -56 + 10.8\,WS$	$CP_R = -208.7 + 45.3\,WS$	$CP_S = -226.203 + 210.4\,WS$
	RH	$CP_W = 60.28 - 0.71\,RH$	$CP_R = 209.0 - 1.6\,RH$	$CP_S = 2101.0 - 15.38\,RH$
Badin	Tmax	$CP_W = -402.9 + 13.8\,T_{max}$	$CP_R = -2392.2 + 76.2\,T_{max}$	$CP_S = 5950.8 - 99.9\,T_{max}$
	Tmin	$CP_W = -111.46 + 8.08\,T_{min}$	$CP_R = -744.4 + 42.5\,T_{min}$	$CP_S = 3615.06 - 47.9\,T_{min}$
	P	$CP_W = 79.07 - 0.07\,P$	$CP_R = 266.7 - 0.42\,P$	$CP_S = 2440.8 - 0.68\,P$
	WS	$CP_W = 140.1 - 10.7\,WS$	$CP_R = 467.6 - 39.9\,WS$	$CP_S = 4105 - 228.9\,WS$
	RH	$CP_W = -81.2 + 3.65\,RH$	$CP_R = -735.4 + 22.9\,RH$	$CP_S - 125.5 + 65.8\,RH$

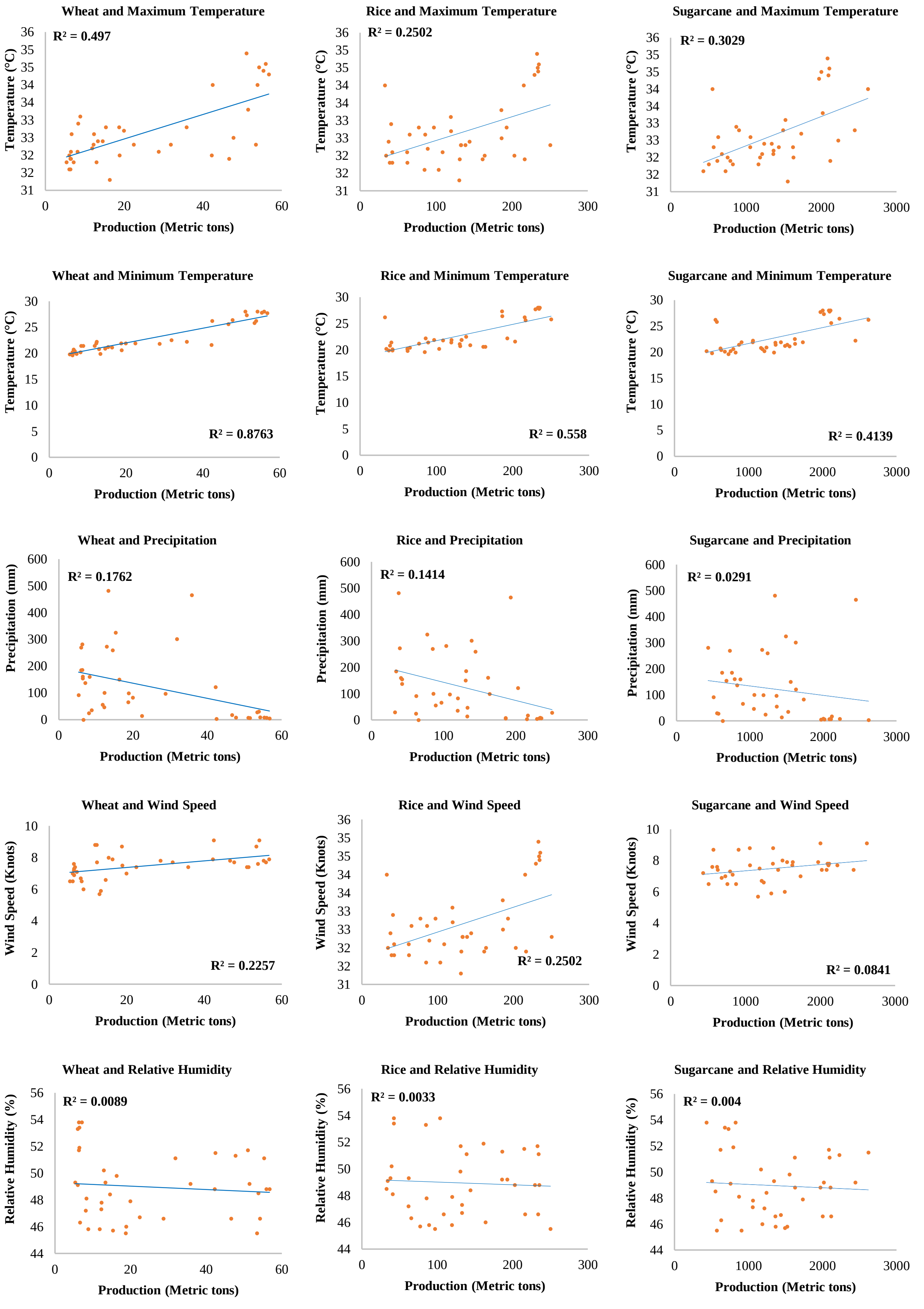

Fig. 7. R^2 statistics for OLSR regression in Thatta.

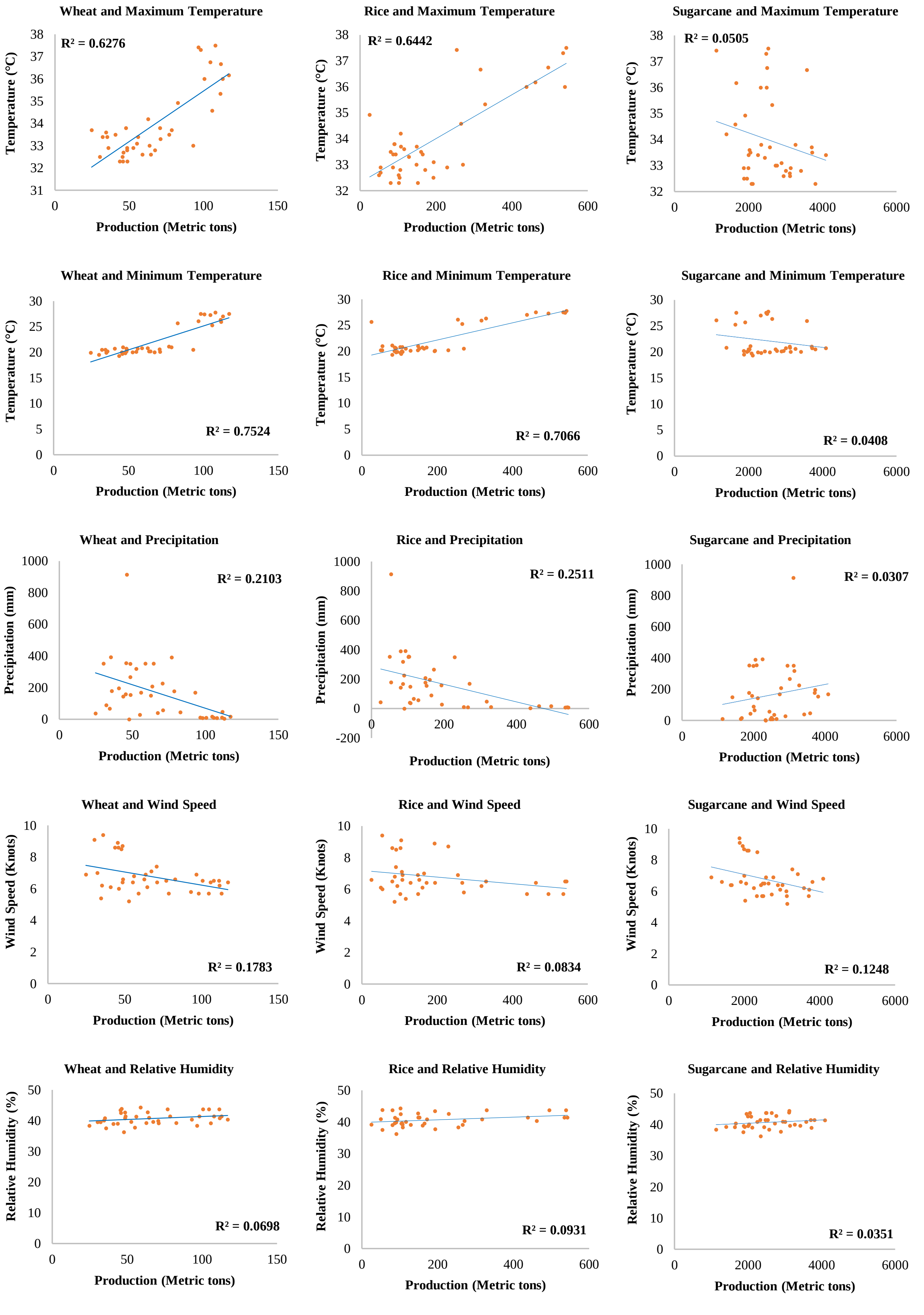

Fig. 8. R^2 trends for OLSR regression in Badin.

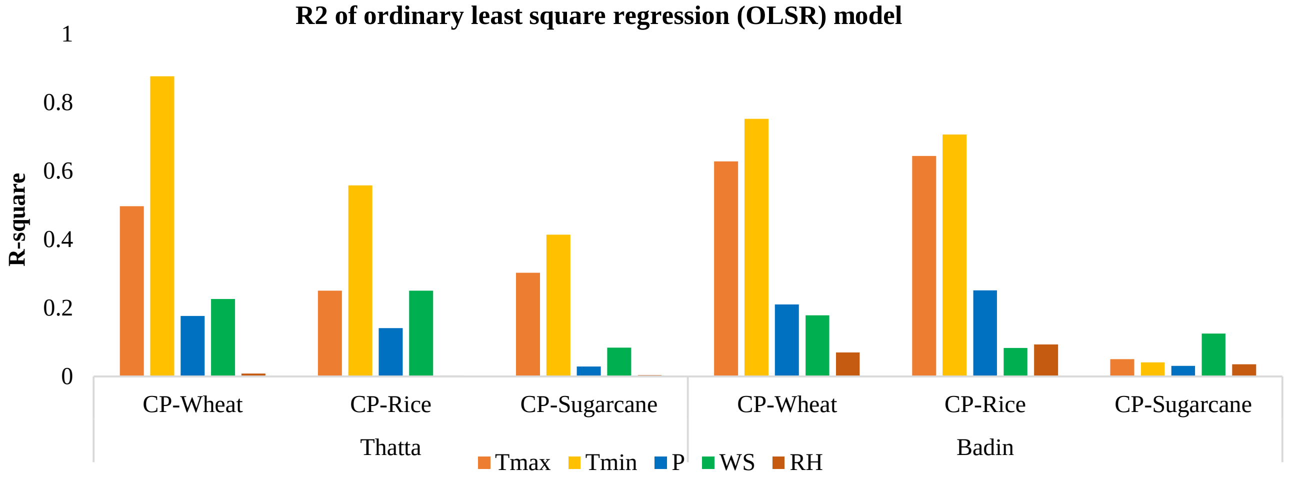

Fig. 9. R^2 statistics for OLSR regression.

Table 4. R^2 of ordinary least square regression (OLSR) model.

Climatological variables	R^2					
	Thatta			Badin		
	CP_W	CP_R	CP_S	CP_W	CP_R	CP_S
Tmax	0.497	0.2505	0.3029	0.6276	0.6442	0.0505
Tmin	0.8763	0.558	0.4139	0.7524	0.7066	0.0408
P	0.1762	0.1414	0.0291	0.2103	0.2511	0.0307
WS	0.2257	0.2505	0.0841	0.1783	0.0834	0.1248
RH	0.0089	0.0033	0.004	0.0698	0.0931	0.0351

Table 5. Multiple linear regression (MLR) model.

	Thatta
CP_W	$CP_{it} = 15. - 4.38\,Tmax_{it} + 7.95\,Tmin_{it} + 0.02\,P_{it} + 0.39\,WS_{it} - 0.69\,RH_{it} + 59.30$
CP_R	$CP_{it} = 168.0 - 21.30T\,max_{it} + 22.81\,Tmin_{it} + 0.06\,P_{it} + 18.80WS_{it} - 0.17\text{ RH }RH_{it} + 441.27$
CP_S	$CP_{it} = -2051.1 + 18.4\,T\,max_{it} + 162.7\,Tmin_{it} + 1.42\text{ PPT }P_{it} + 9.85\text{ WS }WS_{it} - 23.36\,RH_{it} + 4605.17$
	Badin
CP_W	$CP_{it} = -71.23 - 1.78\,Tmax_{it} + 7.64\,Tmin_{it} - 0.02\,P_{it} - 3.3\,WS_{it} + 1.38\,RH_{it} + 136.08$
CP_R	$CP_{it} = -2179.3 + 31.0\,Tmax_{it} + 17.3\,Tmin_{it} - 0.22\text{ PPT }P_{it} + 4.52\,WS_{it} + 23.24\,RH_{it} + 751.75$
CP_S	$CP_{it} = 5268.76 - 55.06\,Tmax_{it} - 91.31\,Tmin_{it} - 0.55\text{ PPT }P_{it} - 308.35\,WS_{it} + 82.49\,RH_{it} + 6181.81$

Table 6. Multiple linear regression (MLR) coefficients and R^2.

Climatological Variables	R^2					
	Thatta			Badin		
	CP_W	CP_R	CP_S	CP_W	CP_R	CP_S
Constant	0.799	0.706	0.659	0.604	0.007	0.400
Tmax	0.026	0.139	0.901	0.687	0.209	0.784
Tmin	0.000	0.000	0.006	0.003	0.203	0.412
P	0.008	0.377	0.071	0.221	0.029	0.499
WS	0.788	0.089	0.930	0.158	0.722	0.006
RH	0.115	0.957	0.488	0.371	0.009	0.242
F	67.924	11.510	5.901	23.155	22.191	2.740
R^2	0.911	0.636	0.472	0.778	0.771	0.293
Adjusted R^2	0.898	0.580	0.392	0.745	0.736	0.186

During harvesting season, rainfall may cause severe damages to the wheat crop and may lead to decline in the production of the wheat (Janjua *et al.*, 2010). Similar pattern was also observed in the study area. In contrast to this study, another study in Sindh showed opposite trends and revealed that increase in rainfall may lead to increase in wheat production in Sindh (Magsi *et al.*, 2018). Ali *et al.*, (2017) reported a decline of 1.9% in wheat production in the country during 2013-2014 to 2014-2015. This study also reported influence of maximum and minimum temperature as significant and negative on the production of wheat, insignificant and negative impact on the production of rice and significant negative impact on the production of sugarcane.

Using Multivariate Linear Regression analysis, another study reported that rise in precipitation has positive impacts on production of rice crop in Larkana and Jacobabad (Rahman *et al.*, 2017).

R^2 value of precipitation with crops shows that in Thatta, production of wheat crop (R^2=0.1762, 17.62%) has greater influence of precipitation as compared to rice (R^2=0.1414, 14.14%) and sugarcane (R^2=0.0291, 2.91%) at the lowest. In Badin, the impact of precipitation is highest for rice (R^2=0.2511, 25.1%) followed by wheat (R^2=0.2103, 21.03%) and sugarcane (R^2=0.0307, 3.07%).

Impact of wind speed on crop production: A contradictory result for the regression was observed among Thatta and Badin for the impacts of wind speed on wheat, rice and sugarcane crop. In Thatta, the results show the linear positive regression between wind speed and agricultural production and in Badin linear negative regression was observed. The value of R^2 shows that influence of wind speed is greater for rice (R^2=0.2505, 25.05%) in Thatta and wheat (R^2=0.1783, 17.83%) in Badin. Variation in the wind speed has direct impacts on the temperature and rainfall, and ultimately the crop production (Palomares-Salas *et al.*, 2014). The similar trend of wind velocity was observed in the present study. In northern areas of Pakistan, high wind speeds consequent to the rise in temperature have caused the crops to be ripen under hot and dry climate (Kazmi & Rasul, 2012).

Impact of relative humidity on crop production: In contrast to wind speed, relative humidity shows explicitly inverse regression in both the districts. Continuous linear negative regression in Thatta and continuous linear positive regression in Badin between wind speed and all crop production variables reflect that wind speed and relative humidity are inverse of each other. Since Thatta is near the coastline, strong winds persist and therefore relative humidity has lesser impacts on the production of crops as compared to wind speed. As compared to other climatological variables, relative humidity has the lowest impact on the crops production in Thatta and Badin. However, it has comparatively higher values of R^2 in Badin as that of Thatta. A study in upper Sindh, in Kambar Shahdadkot district, revealed that production of all crops of the district are under severe threat due to climate change particularly due to relative humidity (Chandio & Anwar, 2009).

Conclusion

In the province of Sindh, particularly coastal districts are facing multiple impacts of climate change over agriculture sector and ultimately resulting into economic fissures. Due to variation in climatological variables sowing, growing and harvesting periods of the agricultural crop productions are gravely disturbed. It can be concluded that many of the impacts of climate change on agriculture sector are channeled in a sequence of number of causes, impacts and disasters. These consequences of consequences of the climate change are need to be regulated by multi-factoral analysis across multiple disciplines. It was found that temperature and precipitation are the highly influencing variables of climate; therefore, geo-spatial, temporal and further extended studies are recommended to conduct across multiple times and space for better validation, accuracy, applications and forecasting.

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