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Impact of Climate Change on Wheat Production in Dinajpur Region of Bangladesh: an Econometric Analysis

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Abstract

Dinajpur is the highest wheat producing northern district in Bangladesh and wheat is the second most essential cereal crop after rice in this country. This is much sensitive to climatic change. The main concern of this paper was to quantify the long-term effect of climate change on wheat production in Dinajpur district using multiple regression analysis technique taking several climatic variables for 1948-2004. The approximately significant effects were found for the climatic variables of average minimum temperature (tmn), average dry bulb temperature (td) and total rainfall (ttr) on wheat production. It may be reported that one percent increase in tmn increases the yield rate by about 2.62%, one percent increase in td decreases the yield rate by about 2.58% and one percent increase in ttr increases the yield rate by about 0.03%.

Key words: Climate change, Econometric analysis, Wheat

Introduction

The global mean temperature has risen by 7°C since 1860. Over the same period, CO_2 concentrations have increased by 46 percent. Global agriculture will face the problems of changing climate in coming decades. Crop yield growth has slowed since 1990. On the other hand, the world population will be double by the year 2060. Despite technological advances such as improved crop varieties and irrigation systems, climate is still the key factor for agricultural productivity. Furthermore, climate may vary and change with time and space but warming may also affect agriculture sector as a whole through changing yields, changing water availability, affecting soil condition, etc. The effect of climate on agricultural productions is important for local, regional, national and global scales. Wheat yield is much sensitive to climate variation and change as the temperature variation is the notable factor for wheat cultivation. There is no universal accepted approach for the assessment the impacts of climate change on agriculture. The three approaches are: (1) Crop yield analysis, (2) Spatial analysis (3) Agriculture system analysis. Impact of climate change on crop growth, development, water use and productivity of crop can be quantified by the measurement of direct effects of modified weather parameters and CO_2 on crop growth in phytotron, glass houses, etc. but these approaches are costly. You L. *et al.* (2005) assessed the impact of climate change on wheat production in China through crop yield analysis where regression technique is used for the historical panel data. Wheat is the second most important cereal crop after rice in Bangladesh and Dinajpur is the highest wheat producing area in this country. So, the multiple regression model using historical climatic and yield data for wheat crops in Dinajpur is used to predict the changes in yields expected due to changes in climate.

A brief discussion on the necessity of the assessment for the impact of climatic change on wheat production in Dinajpur is explained in introductory section. In the section 2, the sources of data are mentioned and the methodologies applied are briefly discussed. The findings of this study are presented in the section 3. The conclusions of this study are presented in the section 4.

Methodology

Sources of data

The secondary data on the production and acreage of wheat were collected from the book ñA Data Base on Agriculture and Food grains in Bangladesh (1947-48 to 1989-90)ò (Hamid M. A. (1991) and ñStatistical Year Book of Bangladeshò published by the Bangladesh Bureau of Statistics (BBS, 1992). The annual data on wheat production in metric ton and in acres were collected for 1947-48 to 2003-2004. The wheat production rate in percentage (wpr) was used in the analysis and it is calculated by a simple formula: Rate = (Annual wheat production / Annual cultivated area) × 100. Data from 1949 to 1990 were taken from the Hamid M. A. (1991) and data from 1991 to 2001 are taken from Statistical Year Book of Bangladesh. The production 13,913 metric ton in 1982 sources from Hamid M. A. (1991) was detected as outlier and that was replaced from the data 1,28,845 metric ton recorded in the Statistical Year Book of Bangladesh (BBS,1992) which was more than 9 times bigger than the earlier value. Again, the highly significant structural change was detected Gujarati, D.N. (1995) in the data from 1976 and a dummy variable (dm) was used for structural change as: dm= 0 for wheat production rate before 1976 and dm=1 for wheat production rate from 1976.

The secondary data on climatic factors of Dinajpur district during 1948-2004 for the wheat growing period (Novemberï March) are collected from the Bangladesh Meteorological Department, Dhaka, Bangladesh. But all the climatic data of Dinajpur were not available for 1973-1980 and these missing data were estimated by applying univariate Box-Jenkinôs ARIMA (autoregressive integrated moving average) modeling techniques Pankraiz (1991). The residualôs stationarity and normality were checked. The outliers were checked in these data and the detected outliers were replaced by the estimated value using the same techniques. In this research, the used climatic variables were the average minimum temperature in celcius (tmn), the average maximum temperature in celcius (tmx), the average dry bulb temperature in celcius (td), the average wet bulb temperature in celcius (tw), the frequency of average dry bulb temperature which is greater than 20^0C (ftd), the total rainfall in millimeter (ttr), the average maximum rainfall in millimeter (mxr), the average frequency of insignificant rainfall which is less than 5mm (rf), the average relative humidity in percentage (hu), the average sea level pressure in millibar (slp), the average cloud in octas (ac), the average maximum wind speed in knots (wmx), the average wind speed in knots (wv) and the average difference of morning and the afternoon relative humidity in percentage {hu(0-12)}.

Method

A multiple regression model was fitted to examine for the rate of wheat production data on climatic variables during November-March over the years 1948-2004. The three regression models were estimated using three predictor sets of historical climatic data. One dummy variable was included with each predictor set as the significant structural change viewed in the response variable from 1976 what was tested according to Gujarati (1995). The predictor set 1 included 15 variables namely dm, tmn, tw, ftd, ttr, td, hu, mxr, tmx, slp, ac, wmx, wv, hu(0-12) and rf. The predictor set 2 included 11 variables namely dm, tmn, tw, ttr, td, hu, tmx, slp, ac, wmx and wv. The predictor set 3 contained 10 variables namely dm, tmn, tw, ftd, ttr, td, hu, tmx, slp and ac.

Multicollinearity was checked in the regression models for selecting the climatic variables through investigating the range of variance inflation factors (VIF). The variables were selected by using the backward elimination procedure started with full equation and dropped one variable at a time against the smallest insignificant t values. This process was stopped for the minimum absolute t- test became greater than 1. Draper N.R and Smith H. (1981). Normality and stationarity for residuals were also checked for selecting the variables. But the residuals followed normality and first order auto-correlated structure. So it was tried to refit and reexamine the new regression coefficients taking the autocorrelation into account. The new regression models were estimated according to Cochrane and Orcutt (1949) iterative procedure, which satisfied the assumption of uncorrelated errors with the same procedure. To obtain robust models, outliers and hi-leverage points were identified applying some modern diagnostics tools namely deleted Studentized residuals and other residual based techniques. Chatterjee, S. and Hadi, A. S. (1988). Finally the three appropriate models were obtained and among the three obtained models, one model was selected having the highest F and R^2 values.

Results

In order to quantify the impact of climatic change on wheat production in Dinajpur district of Bangladesh, three multiple regression models are made taking several climatic variables during wheat growing period (Nov-Mar) including a dummy variable (dm). Dummy variable is taken for the structural change of wheat production data in 1976. The estimated regression coefficients for the selected (original) variables are presented in Table 1 for the three data sets 1, 2 and 3. Furthermore, Table 2 presents the regression coefficients of the models for the transformed variables.

Table 1. Regression coefficients for the selected variables of the three data sets 1, 2 and 3

Set 1					Set 2					Set 3				
pred	**coef**	**sd**	**t**	**p**	**pred**	**coef**	**StDev**	**t**	**p**	**pred**	**coef**	**sd**	**t**	**p**
Const	34.72	41.35	0.84	0.405	Const	55.69	40.9	1.36	0.179	Const	34.62	41.55	0.83	0.409
dm	50.231	3.083	16.29	0	dm	50.267	3.128	16.07	0	dm	50.469	3.113	16.21	0
tmn	5.965	1.87	3.19	0.002	tmn	5.551	1.854	2.99	0.004	tmn	5.881	1.882	3.12	0.003
ftd	-0.6013	0.4596	-1.31	0.197	ttr	0.04692	0.02918	1.61	0.114	ftd	-0.6301	0.4605	-1.37	0.177
tmx	-2.621	1.363	-1.92	0.06	td	-1.55	1.453	-1.07	0.291	ttr	0.0415	0.02875	1.44	0.155
ac	-8.49	4.674	-1.82	0.075	tmx	-2.332	1.462	-1.6	0.117	tmx	-2.553	1.375	-1.86	0.069
mxr	0.3566	0.2257	1.58	0.12	ac	-9.342	4.649	-2.01	0.05	ac	-8.543	4.708	-1.81	0.076

Const –Constant, pred-predictor, coef-coefficient, sd-standard deviation, t-t value, p-p value

Table 2. Regression coefficients for the transformed variables of three data sets 1, 2 and 3

Set 1					Set 2					Set 3				
pred	**coef**	**sd**	**t**	**p**	**pred**	**coef**	**sd**	**t**	**p**	**pred**	**coef**	**sd**	**t**	**p**
const	25.75	16.87	1.53	0.133	const	37.93	17.24	2.2	0.033	const	25.96	17.67	1.47	0.148
dm*	46.876	3.619	12.95	0	dm*	47.163	3.725	12.66	0	dm*	47.111	3.637	12.95	0
tmn*	2.805	1.904	1.47	0.147	tmn*	2.675	2.04	1.31	0.196	tmn*	2.639	1.915	1.38	0.174
ftd *	-0.4907	0.4457	-1.1	0.276	tr*	0.04336	0.02131	2.03	0.047	td *	-0.5244	0.4522	-1.16	0.252
tmx*	-1.875	1.277	-1.47	0.148	td*	-1.81	1.859	-0.97	0.335	ttr*	0.04087	0.02116	1.93	0.059
ac*	-3.291	4.084	-0.81	0.424	tmx*	-1.57	1.344	-1.17	0.248	tmx*	-1.738	1.294	-1.34	0.185
mxr*	0.3786	0.1681	2.25	0.029	ac*	-3.856	4.134	-0.93	0.356	ac*	-2.998	4.153	-0.72	0.474

** is used for transformed variables*

Table 3 presents the identified outliers and hi-leverage points for the regression models. Two (2) outliers (the 50th and 56th observations) and two (2) hi-leverage points (28th and 29th observations) were detected for all the models of the transformed variables and those unusual observations were omitted to obtain the appropriate regression models by deleting the 56th, 50th, 29th and then 28th observations one after another. The TS plots of the deleted Studentized residuals for the regressions of the transformed variables of the data sets 1, 2 and 3 indicated unusual point along the X-axis and the figures showed only one unusual point at a time in each case. NP plots for residuals followed normality and ACF displays for residuals showed non auto correlated structure (approximately) for the fitted models after deleting the 4 unusual points. Some residual figures for the data set 2 are presented [Figure 1 to Figure 12]. Table 4 presents the ANOVA (analysis of variance) results for the obtained regression models where the detected outliers and hi-leverage points had been deleted one by one.

Table 3. Identification of outlier and hi-leverage points in the transformed regression models

	n =56, p=3,(3p/n)=0.375,			n=55 p=3,(3p/n)=0.382			n=54 p=3,(3p/n)=0.389			n=53 p=3,(3p/n)=0.396,		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
Obs. no	56	56	56	50	50	50	29	29	29	28	28	28
SRES1	-2.687	-2.722	-2.630	2.694	2.576	2.617	-1.222	-1.655	-1.363	-1.446	-1.512	-1.374
TRES1	-2.880	-2.924	-2.809	2.893	2.746	2.797	-1.229	-1.687	-1.376	-1.464	-1.534	-1.388
HI1	0.074	0.085	0.084	0.065	0.072	0.068	0.489	0.425	0.469	0.457	0.449	0.453

n-o. of observation, p= parameter, Obs. no-Observation number, HI -Hi-leverage points, SRES-Standardized residuals, TRES-T resid

Table 4. ANOVA results for the regression models of data sets 1, 2 and 3 deleting UO

		DF	TSS	RSS	RMS	ESS	EMS	DF	F	P	S	R-Sq	R-Sq(adj)	DW
1	56 O del	54	11028.9	9441.9	1573.6	1587	33.1	48	47.6	0	5.75	85.60%	83.80%	1.38
	50 O del	53	10304.8	8957.7	1493	1347	28.7	47	52.09	0	5.354	86.90%	85.30%	1.4
	29 HL del	52	10248	8943.8	1490.6	1304.2	28.4	46	52.58	0	5.325	87.30%	85.60%	1.41
	28 HL del	51	9578.8	8333.9	1389	1244.9	27.7	45	50.21	0	5.26	87.00%	85.30%	1.32
2	56 O del	54	11316.2	9676.6	1612.8	1639.6	34.2	48	47.21	0	5.845	85.50%	83.70%	1.4
	50 O del	53	10580.4	9167.5	1527.9	1412.9	30.1	47	50.83	0	5.483	86.60%	84.90%	1.42
	29 HL del	52	10521.7	9191.1	1531.8	1330.6	28.9	46	52.96	0	5.378	87.40%	85.70%	1.4
	28 HL del	51	9860.8	8596.3	1432.7	1264.5	28.1	45	50.99	0	5.301	87.20%	85.50%	1.29
3	56 O del	54	11498.9	9847.9	1641.3	1650.9	34.4	48	47.72	0	5.865	85.60%	83.80%	1.42
	50 O del	53	10755.7	9340.3	1556.7	1415.4	30.1	47	51.69	0	5.488	86.80%	85.20%	1.45
	29 HL del	52	10695.6	9336.2	1556	1359.4	29.6	46	52.65	0	5.436	87.30%	85.60%	1.44
	28 HL del	51	10039.9	8736.2	1456	1303.7	29	45	50.26	0	5.382	87.00%	85.30%	1.37

**UO-Unusual Observations,O del-Outlier deleted, HL del-High-Leaverage deleted, TSS-total sum square, RSS-Regression Sum Square, RMS-Regression Mean Square, ESS-Error Sum Square, EMS-Error Mean Square, DW-Durbin Watson Statistic, DF-Degrees of Freedom*

Table 4 presents the finally fitted regression coefficients deleting the unusual observations. But from the regression results for all sets of data, no significant regression coefficient of climatic variables was observed at 5% level of significance. On the other hand, the significant t values were found only for the coefficient of dummy (dm*) variable. The model for the data set 2 was selected among the three models based on the highest F and R^2 and the finally obtained coefficients of finally selected variables dm*, tmn*, td*, ttr* tmx* ac* are 50.58, 2.62, -2.58, 0.0312, -1.22 and -3.58, respectively, and the corresponding t values were 12.39, 1.5, 1.55, 1.63, 0.87 and 0.99 in absolute term. The t values are less than one for the coefficient of tmx* and ac*. According to the results of the model, highly significant effect was found for dm* and approximately significant effect is obtained for the climatic variables of tmn*, td* and ttr*. So, one percent increase in the dummy variable (dm*) increases the yield rate by about 50%, one percent increase in average minimum temperature (tmn) increases the yield rate by about 2.62%, one percent increase in average dry bulb temperature (td) decreases the yield rate by about 2.58% and one percent increase in total rainfall (ttr) increases the yield rate by about 0.03%.

Table 5. Regression coefficients for the three fitted models deleting unusual observations

Set 1					Set 2					Set 3				
pred	**coef**	**sd**	**t**	**p**	**pred**	**coef**	**sd**	**t**	**p**	**pred**	**coef**	**sd**	**t**	**p**
const	23.4	18.85	1.24	0.221	const	40.88	16.71	2.45	0.018	const	25.5	19.69	1.3	0.202
dm*	50.035	4.084	12.25	0	dm*	50.582	4.081	12.39	0	dm*	49.912	4.116	12.13	0
tmn*	2.183	1.647	1.33	0.192	tmn*	2.62	1.745	1.5	0.14	tmn*	2.028	1.665	1.22	0.229
ftd *	-0.4759	0.4231	-1.12	0.267	ttr*	0.03127	0.01912	1.63	0.109	ftd*	-0.482	0.4313	-1.12	0.27
tmx*	-1.427	1.397	-1.02	0.313	td*	-2.583	1.667	-1.55	0.128	ttr*	0.03021	0.01942	1.56	0.127
ac*	-3.316	3.568	-0.93	0.358	tmx*	-1.22	1.404	-0.87	0.389	tmx*	-1.443	1.428	-1.01	0.317
mxr*	0.3056	0.1539	1.99	0.053	ac*	-3.581	3.605	-0.99	0.326	ac*	-2.924	3.649	-0.8	0.427

Residual plots for data Set 2

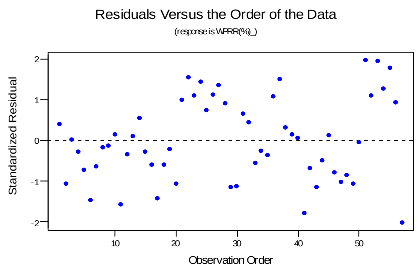


Fig. 1. SR vs order of the data for original data

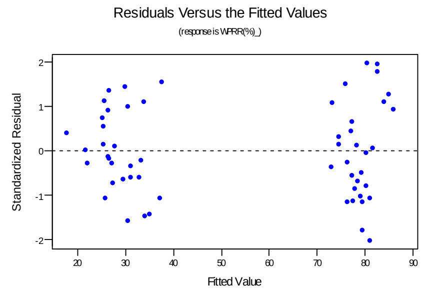


Fig. 2. SR vs fitted value for original data

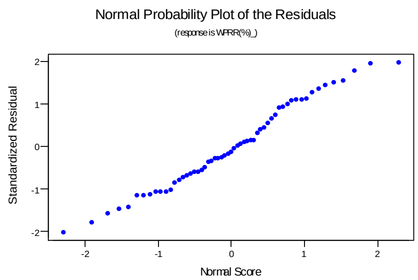
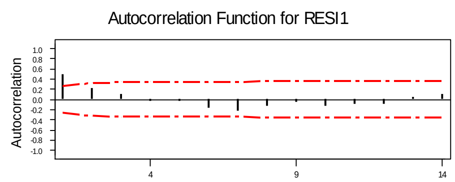


Fig. 3. Np plot of SR for original data



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.50	3.74	14.75	8	-0.13	-0.76	25.40
2	0.23	1.43	18.04	9	-0.04	-0.23	25.51
3	0.11	0.65	18.77	10	-0.13	-0.72	26.69
4	-0.03	-0.18	18.83	11	-0.08	-0.45	27.18
5	-0.03	-0.17	18.89	12	-0.08	-0.45	27.67
6	-0.17	-0.99	20.73	13	0.04	0.23	27.81
7	-0.23	-1.31	24.15	14	0.10	0.56	28.61

Fig. 4. ACF plot of SR for original data

Note: SR-Standardized residuals, ACF-Auto correlation function, DR-Deleted residuals, Np-Normal probability

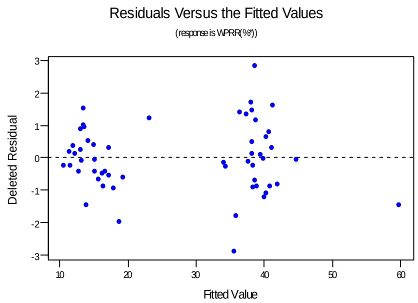


Fig. 5. DR vs fitted value for transformed data

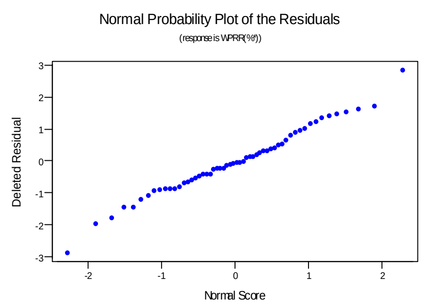


Fig. 6. Np plot of DR for transformed data

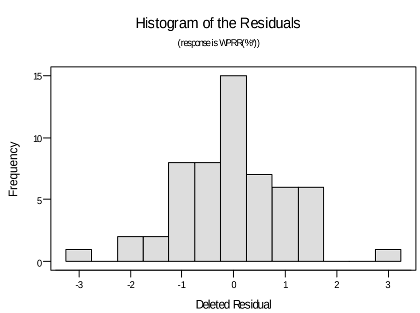
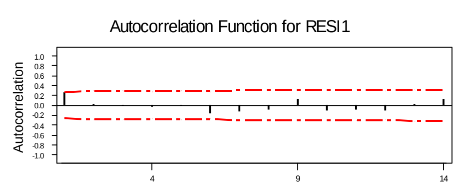


Fig. 7. Histogram of DR for transformed data



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.26	1.97	4.08	8	-0.09	-0.60	7.75
2	0.03	0.24	4.16	9	0.12	0.78	8.70
3	-0.01	-0.08	4.16	10	-0.11	-0.70	9.49
4	-0.04	-0.27	4.26	11	-0.09	-0.58	10.05
5	-0.01	-0.08	4.27	12	-0.10	-0.65	10.79
6	-0.17	-1.20	6.18	13	0.03	0.16	10.84
7	-0.12	-0.85	7.21	14	0.13	0.86	12.19

Fig. 8. ACF plot of DR for transformed data

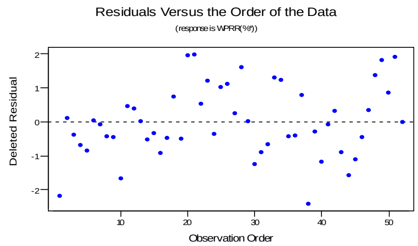


Fig. 9. DR vs fitted value deleting 28th obs.

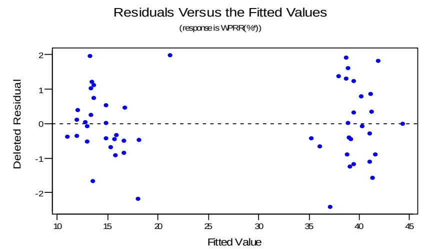


Fig. 10. Np plot of DR deleting 28th obs.

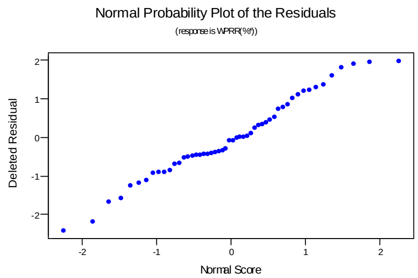
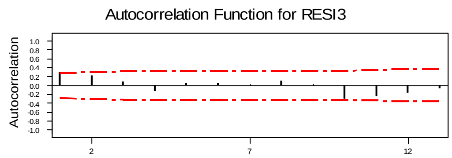


Fig. 11. Hist. of DR deleting 28th obs.



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.30	2.16	4.93	8	0.12	0.73	10.25
2	0.22	1.43	7.53	9	0.00	0.02	10.25
3	0.09	0.57	8.00	10	-0.29	-1.81	16.01
4	-0.13	-0.84	9.02	11	-0.25	-1.44	20.18
5	0.06	0.35	9.21	12	-0.17	-0.93	22.12
6	0.05	0.32	9.37	13	-0.07	-0.41	22.52
7	0.02	0.10	9.38				

Fig. 12. ACF plot of DR deleting 28th obs.

Conclusions

In order to quantify the impact of climatic change on wheat production in Dinajpur district of Bangladesh, three multiple regression models are made taking several climatic variables during wheat growing period (Nov-Mar) including a dummy variable. According to the results of the model, highly significant effect is found for the dummy variable dm where one percent increase in dm increases the yield rate by about 50%. So it may be mentioned that the improved technology such as high yielding variety, irrigation system and other physical inputs may contribute positively to the wheat production and yield rate. Furthermore, approximately significant effect is obtained for the climatic variables of average minimum temperature (tmn), average dry bulb temperature (td) and total rainfall (ttr) and it may be concluded that one percent increase in tmn increases the yield rate by about 2.62%, one percent increase in td decreases the yield rate by about 2.58% and one percent increase in ttr increases the yield rate by about 0.03%.

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