African Journal of Agricultural Research Vol. 5(22), pp. 3017-3025, 18 November, 2010
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X ©2010 Academic Journals

Full Length Research Paper

Impact of weighted rainfalls on the yield of wheat in the Punjab, Pakistan

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Accepted 2 September, 2010

A study of weighted rainfalls, which is almost unprecedented effort in agricultural statistics, was conducted to develop a mechanism to assign weights to different amounts of rainfalls proportional to their importance/need of time with reference to the crop condition. It is a methodology for determination of weights assigned to amounts of rainfalls of different months of Rabi season that have a significant impact on the yield of wheat crop. The data of rainfalls from 2000 - 2001 to 2006 - 2007 at seven observatories of Meteorological Department, Punjab and wheat production of respective districts were used. It was observed that as the rainfalls in the important months of Rabi season are increased; the average yield of wheat also increases. But at a certain level, excess rainfalls cause a decline in the yield. The suitable quadratic models were fitted independently between yield and amount of rainfalls for each month of the season. In each case explained variation R^2 was used as a proposed weight to the rainfall of the relevant Rabi month. The empirical study supported the use of weighted rainfalls instead of total rainfalls of Rabi season. The concept of weighted rainfall was also proved effective in estimating the crop production through a statistical model.

Key words: Barani area, district, division, kharif season, maund, rabi season.

INTRODUCTION

Area of Pakistan is 796,096 km² and the population is almost 170 million. The country has four provinces namely Sindh, Punjab, Khyber Pakhtoonkhwa (formerly NWFP) and Balochistan. The Punjab being the second largest (area of Punjab is 205,345 km²) and the most agricultural province of the country, contributes almost 75% to wheat production of Pakistan.

There are two zones of the Punjab: lower and Upper Punjab. In Kharif season (May to September), rice crop is sown in the upper and cotton is sown in the lower Punjab. Wheat crop is sown in Rabi season (October to April) throughout the province. Sowing of wheat starts from late October and continues maximum at the end of December. Harvesting of wheat starts from beginning of April and completes maximum at the end of the same month.

Yield of wheat is highly influenced by the timely rainfalls during the Rabi season. Firstly, a light rainfall is essential for moisture in the soil at the sowing time, secondly at the tillerring stage and thirdly at the time of development of grain.

There are two major categories of area in the Punjab: irrigated and Barani (un-irrigated). In irrigated area, there is availability of canal as well as tube-well water, so farmers are comparatively less dependent on the rainfalls. But in case of Barani areas, crops are totally dependent on timely rainfalls as there is no availability of any other source of water except rainfalls. The most of the upper Punjab area is hilly and Barani. The Punjab is administratively and geographically divided into 34 districts and 8 zones (each zone is called a Division). Each Division comprises 3 to 4 districts having meteorologically identical state. The name of District-Headquarter of a division is same as the division. Maps of Pakistan and Punjab showing all neighboring countries and allocation of all the districts of the province respectively are given for illustration (Figure 1).

Objective of the study

The objective of the study is to develop a statistical model for the projection of wheat yield. Amounts of rainfalls in

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Figure 1. Punjab (districts).

Table 1. Average Rainfalls (mm) in the months recorded at 7 observatories of Metrological Department in the Punjab from 2000 - 2001 to 2006 - 2007.

Months	Mean	S.D
Oct	11.204	21.427
Nov	4.042	10.109
Dec	6.400	10.483
Jan	26.646	35.185
Feb	32.179	47.758
Mar	25.271	24.205
Apr	13.808	13.931

each Rabi month are used as explanatory variables. But wheat crop needs water at its three main stages as discussed earlier: It leads the requirement to differentiate various amounts of rainfalls during the whole Rabi season on the basis of their time suitability. Instead of using total rainfall of the season as a predictor variable, it is suggested to use weighted rainfall in the model, so that better estimates of wheat production can be obtained.

A PROPOSED METHODOLOGY

For the determination of weights to rainfalls, a data of rainfalls from 2000 - 2001 to 2006 - 2007 at seven observatories, located at districts Jhelam, Sialkot, Lahore, Sargodha, Faislabad, Multan and Bahawalpur of Meteorological Department of Punjab were used. These seven observatories, scattered throughout the province, depict the whole meteorological position of the Punjab. Table 1 shows average rainfalls (mm) in the Rabi months recorded at seven observatories of Metrological

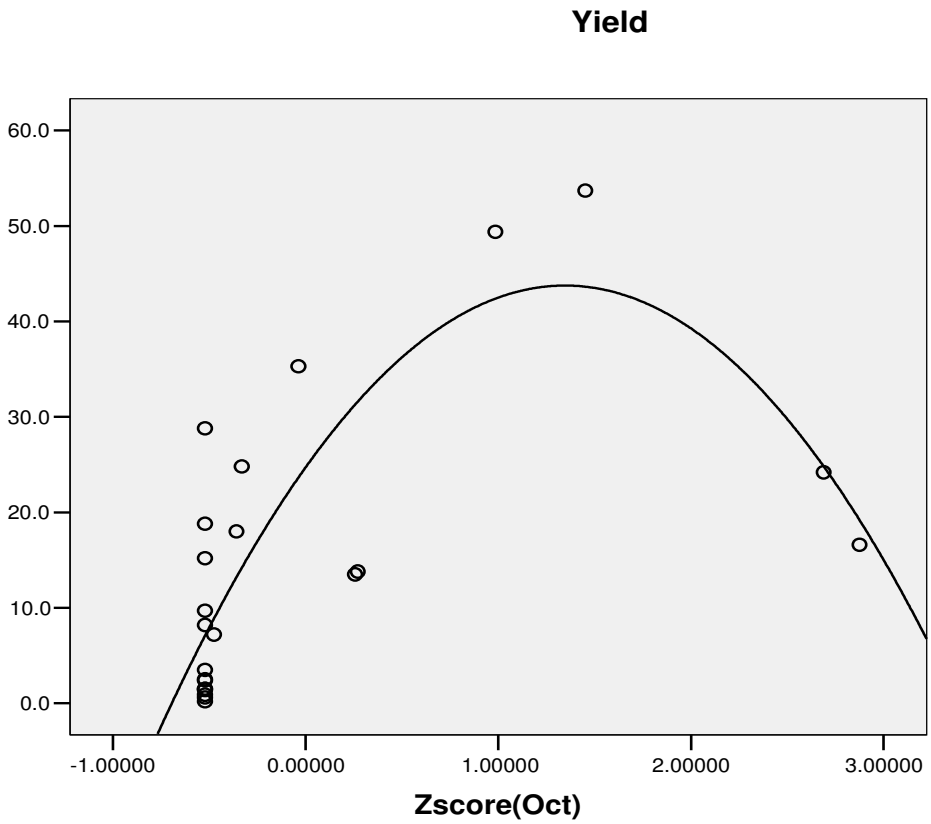

Figure 2. Standardized rainfalls of October and yield of wheat.

Department in the Punjab from 2000 - 2001 to 2006 - 2007 (Table 1).

Along with the rainfalls data, wheat yield data of the respective districts for the year 2000-01-2006-07 also were collected and it was observed that as the rainfalls in the important months of Rabi season are increased, the average yield of wheat also increases. But at a certain level, excess rainfalls cause the decline in the yield as shown in the Figures 2 and 3 for the months of October and February respectively. It is also evident from the graphical presentation that the relationship between average yield of wheat and rainfalls is quadratic rather linear (Figures 2 and 3).

Table 2 shows a comparison between fitting of linear and quadratic models between average yield of the district and the total rainfalls (mm) for each Rabi month. The results given in Table 2 show that quadratic model explained more variation in the total yield of wheat as compared to the linear models except for the month of March. In case of quadratic, the values of R^2 (proportion of explained variation by the model) are higher than linear case and also mostly models are significant (Table 2).

It is evident from the results, as discussed earlier, that rainfalls of October, November and January are explaining more variation in the yield according to the maturity levels of the crop. But at the start of March, the crop is in such maturity level where rainfall has less impact on the yield. Resultantly R^2 of March and April are minimum. An empirical study was conducted taking the value of R^2 of the respective month of the Rabi season as a weight to the rainfall of the month.

EMPIRICAL STUDY

Meteorological status of eight Divisions of the Punjab is different, especially in case of upper and lower Punjab. For empirical study, two Divisions, namely Gujranwala from lower and Rawalpindi from upper Punjab were selected. The yield of a crop in Pakistan is mostly measured in *'maund'* (1 maund = 37.3242 Kg) and the area of a crop in *'acre'* (1 acre = 198 × 220 ft^2).

For the study, secondary data of yield of wheat for the Rabi season 2007 to 2008 from Agriculture Department, Government of the Punjab and rainfall data from Meteorological Department, Government of Pakistan, were used. Data was taken from an attached wing of Agriculture Department, Government of the Punjab, named as Crop Reporting Service (CRS) Punjab. The wing CRS is the largest statistical organization of the Punjab and is fully responsible for handling of all kinds of agricultural statistics of the province on the basis of

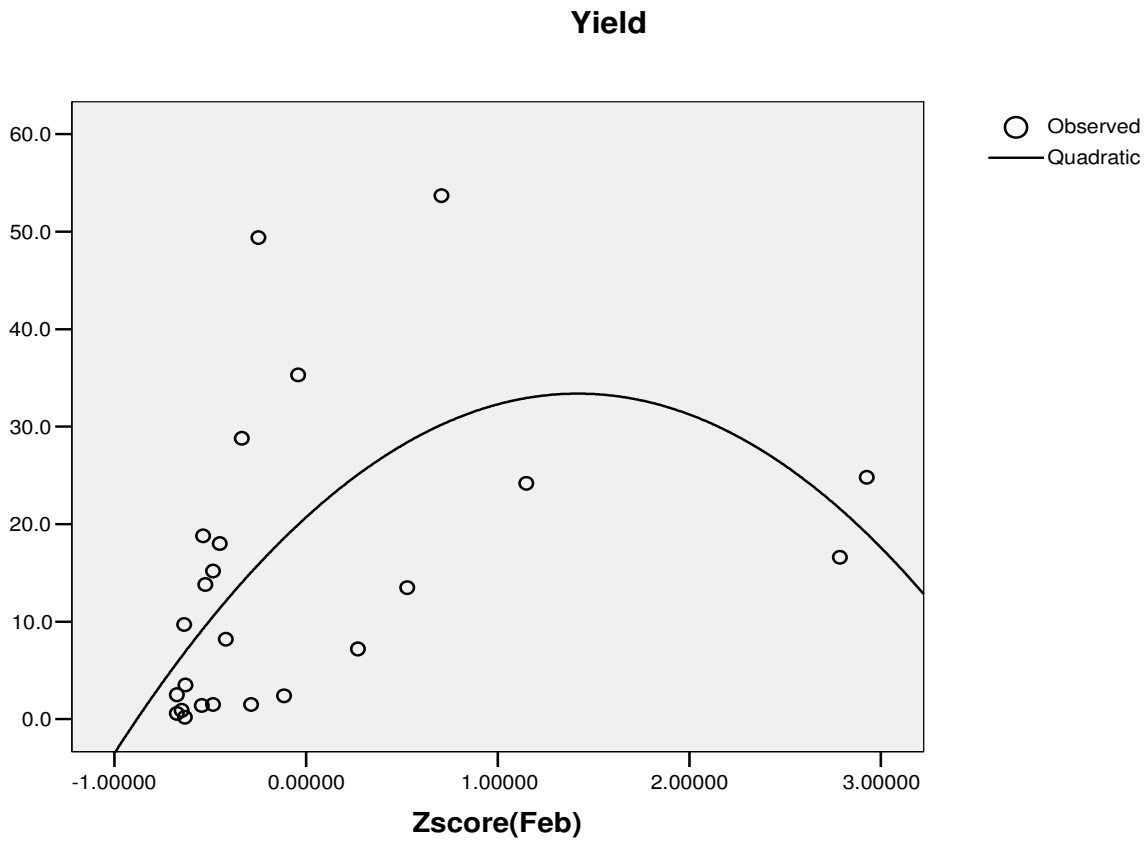

Figure 3. Standardized rainfalls of February and yield of wheat.

Table 2. Linear and quadratic model building between average yield and total rainfalls in the Rabi months recorded at 7 observatories of Metrological Department in the Punjab from 2000 to 2006.

Months	Linear			Quadratic		
	R^2	F	Sig	R^2	F	Sig
Oct	0.260	7.748	0.011	0.614	16.700	0.000
Nov	0.235	6.769	0.016	0.378	6.372	0.007
Dec	0.055	1.284	0.269	0.301	4.522	0.023
Jan	0.625	36.720	0.000	0.668	21.155	0.000
Feb	0.120	3.014	0.097	0.292	4.325	0.027
Mar	0.084	2.016	0.170	0.084	0.967	0.397
Apr	0.154	3.990	0.058	0.155	1.930	0.170

Response variable: Total yield of the district Explanatory variable: Total Rainfall in the month.

sample villages.

CRS selected a sample of 1086 villages from the province using stratified random sampling considering area of wheat / cotton / rice crops as stratification factor. Each district of the province was taken as a 'stratum' and the share of sample size from each stratum was calculated using proportional allocation method. Therefore districts, which are agriculturally rich, have more number of villages as sample. But districts, which have less cropped area of wheat/cotton/rice, consequently have less number of villages in the sample.

In both Rabi/Kharif seasons, surveys are conducted in these villages and parameters of acreage / production for each crop are estimated on the basis of sample statistics. For preparing estimates of production of a crop, six randomly selected plots of size (15 × 20 ft^2) in each

Table 3. Total rainfalls and average yield of the districts of Gujranwala.

Districts	Total rainfalls (mm)	Average yield (m/ac)
Gujranwala	108	32.52
Gujrat	39	21.38
Sialkot	119	27.30
Narowal	114	21.38
Hafizabad	83	30.20
MBDin	176	28.21

Division for the Rabi season 2007 – 2008.

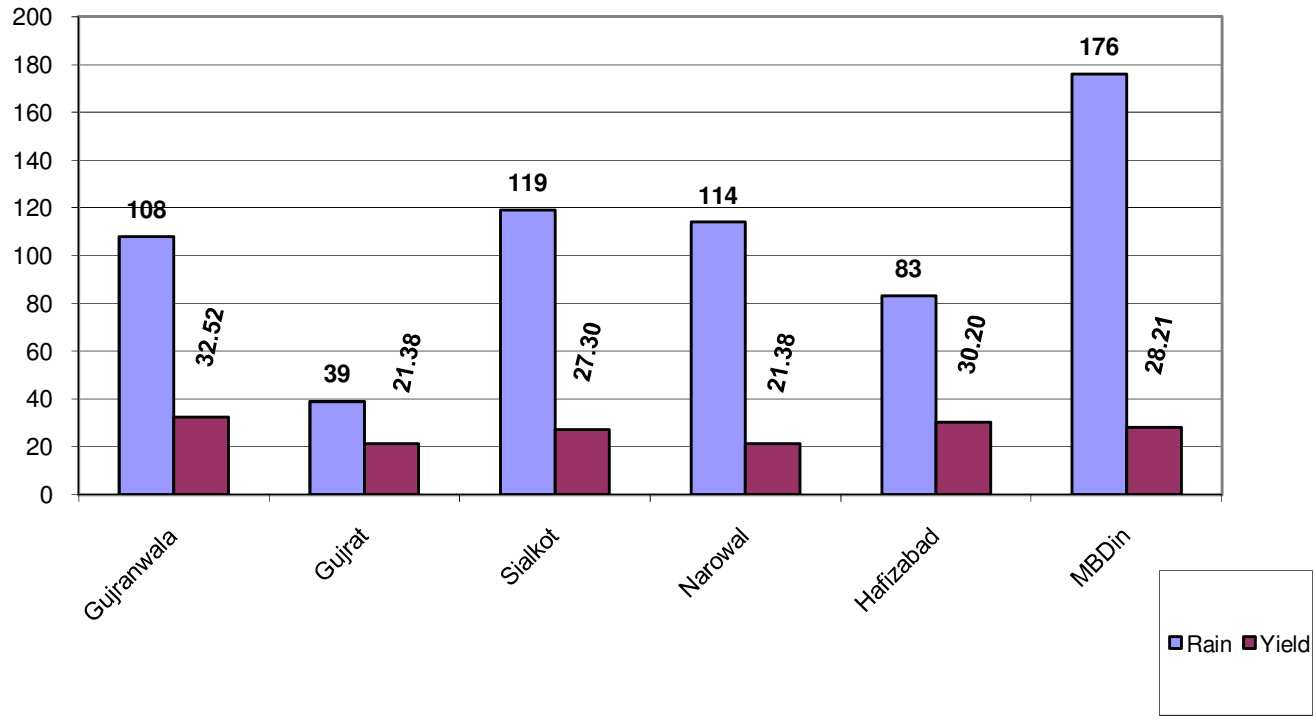

Figure 4. Total rainfalls and average yield of wheat in Gujranwala Division for year 2007-2008.

sample village are harvested.

Gujranwala Division

Gujranwala Division is the biggest Division of the Punjab, as it comprises maximum six Districts named as Gujranwala, M.B.Din, Gujrat, Hafizabad, Sialkot and Narowal. Data of wheat yield from 1050 randomly selected plots from 175 sample villages, covering the whole Division, were used.

Table 3 shows the average yield of wheat and total rainfalls in the respective Districts of the Division during the whole Rabi season 2007 - 2008 (Table 3). Also Figure 4 is a graphical presentation of Total Rainfalls and Average Yield (m/ac) (Figure 4).

The coefficient of simple correlation between Average Yield and Total Rainfalls is 0.346 and Rank coefficient of correlation is 0.143. From Table 3, it can be observed that the maximum rainfall is in District M.B.Din but maximum average yield is in Sialkot. The second lowest rainfall is in Hafizabad with the second highest average yield. It all depends upon the timely rainfalls, not on the amount of total rainfall.

Table 4 shows the distribution of total rainfalls according to the months of Rabi season 2007 - 2008. It can be observed that in the district M.B.Din, contribution of April's rainfall is 70% in the total rainfalls of Rabi season. But in April, wheat crop is in its final maturity level and hence needs no rainfall (Table 4). To incorporate the importance of rainfall of a particular month, values of R^2 from Table 2 against quadratic models

Table 4. Monthly total rainfalls of the districts of Gujranwala Division for the Rabi season 2007-2008.

Actual rainfalls (mm)								
Districts	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total**
Gujranwala	0	6	0	54	5	0	43	108
Gujrat	0	0	0	27	0	0	12	39
Sialkot	0	0	6	71	9	0	33	119
Narowal	0	0	3	52	10	0	49	114
Hafizabad	0	0	0	40	9	0	34	83
MBDin	0	0	0	33	20	0	123	176

Table 5. Rabi months 2007-2008 and their weighted rainfalls of Gujranwala Division.

Weighted rainfalls								
Districts	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total**
Gujranwala	0.000	3.684	0.000	36.072	1.460	0.000	6.665	47.881
Gujrat	0.000	0.000	0.000	18.036	0.000	0.000	1.860	19.896
Sialkot	0.000	0.000	1.806	47.428	2.628	0.000	5.115	56.977
Narowal	0.000	0.000	0.903	34.736	2.920	0.000	7.595	46.154
Hafizabad	0.000	0.000	0.000	26.720	2.628	0.000	5.270	34.618
MBDin	0.000	0.000	0.000	22.044	5.840	0.000	19.065	46.949

Table 6. Barani area of Gujranwala Division for Rabi season 2007-2008.

Districts	Total rainfall (mm)	Weighted rainfall	Average yield (m/ac)
Gujrat	39	19.896	9.87
Sialkot	119	56.977	22.47
Narowal	114	46.154	16.74
Hafizabad	83	34.618	9.44

are used as weights for the rainfall of the respective month.

Table 5 shows the weighted rainfalls of all the Rabi months in 2007 to 2008 in Gujranwala Division. Now the simple and rank coefficients of correlation between average yield and weighted rainfalls are 0.404 and 0.430 respectively, which are better than the coefficients between average yield and actual rainfalls. (Table 5) To check the real impact of weighted rainfalls, a case of Barani (un-irrigated) area of Gujranwala Division is discussed. Out of six districts of the Division, two districts, Gujranwala and M.B.Din, are totally irrigated. But other four districts are partially irrigated as well as Barani (Table 6).

Table 6 shows average yield of wheat of Barani area of the Division, Actual Rainfalls and Weighted Rainfalls. The simple and rank coefficients of correlation between Actual Rainfalls and Yield are 0.813 and 0.800 respectively, where as between weighted rainfalls and yield are 0.912 and 0.800 respectively. It shows a significant increase of association between Weighted Rainfalls and Average Yield.

Rawalpindi Division

Rawalpindi Division is situated near capital of the country, Islamabad. It is mostly a Barani and hilly area. Because level of groundwater is considerably low, so there is rare availability of tube-well and canal water throughout the Division. Agricultural activities of the Division are totally dependent on timely rainfalls. There are four Districts namely Rawalpindi, Jhelam, Chakwal and Attock in the Division. Average yield of wheat of Rawalpindi Division is minimum in the Punjab, as it mostly comprises Barani area.

A data of wheat yield from 522 randomly selected plots from 87 sample villages, covering the whole Division, were used. Table 7 shows actual rainfalls of the Rabi months and average wheat yield of each district of the

Table 7. Districts average yield and total monthly rainfalls for Rabi season 2007 - 2008 in Rawalpindi Division.

	Actual rainfalls (mm)								
Districts	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total rainfalls**	**Avg. yield (m/ac)**
Rawalpindi	0.0	13.0	0.0	107.0	41.0	16.0	98.0	275.0	4.48
Jhelam	0.0	5.0	0.0	57.0	16.0	12.0	114.0	204.0	3.36
Chakwal	0.0	5.0	0.0	38.0	15.0	11.0	58.0	127.0	3.18
Attock	0.0	27.0	0.0	32.0	28.0	10.0	136.0	233.0	3.20

Table 8. Districts average yield and weighted monthly rainfalls for Rabi season 2007 - 2008 in Rawalpindi Division.

	Weighted rainfalls								
Districts	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total weighted rainfalls**	**Avg. yield (m/ac)**
Rawalpindi	0.000	4.914	0.000	71.476	11.972	1.344	15.190	104.896	4.48
Jhelam	0.000	1.890	0.000	38.076	4.672	1.008	17.670	63.316	3.36
Chakwal	0.000	1.890	0.000	25.384	4.380	0.924	9.000	41.578	3.18
Attock	0.000	10.206	0.000	21.376	8.176	0.840	21.080	61.678	3.20

Table 9. Association between Punjab Districts average yield and actual/ weighted rainfalls.

Rank coefficients of correlation between yield (m/ac) and rainfalls (mm)		
Area type	**Rainfalls**	
	Actual	**Weighted**
Irrigated	0.10	0.23
Un-irregated	0.29	0.80

Division. The simple and rank coefficients of correlation between average yield and actual rainfalls are 0.723 and 0.800 respectively (Table 7).

From Table 7, it is evident that the third highest rainfall is of district Jhelam but has second highest average yield. Similarly the district Attock has second highest rainfall but third highest average yield. The reason is that in the important month of Rabi season, January, there is 57 mm rainfall in Jhelam as compared to 32 mm of rainfall in Attock. Implementing the weighted methodology for rainfalls, the results are given in Table 8. The simple and rank coefficients of correlation between average yield and weighted rainfalls are 0.951 and 1.000 respectively. Now the situation is quite different. All the average yields are according to the amounts of weighted rainfalls. Both coefficients of correlation are considerably very high.

Punjab level results

The data of wheat production in the year 2007 to 2008 of 1086 sample villages and yield of 6516 randomly selected plots were used in the provincial level study.

Number of waters and rainfalls

According to the Punjab climate, three waters are essential for wheat crop throughout the Rabi season. In irrigated area farmers are comparatively less dependent upon rainfalls as they have other sources of watering. However, total number of waters to the crop is mainly dependent on the timely rainfalls. In case of timely rainfalls, cost of watering is saved and the crop receives rather better natural water. But in case of no, less or out time rainfalls, farmers have to increase the number of waters to keep the crop germination momentum. It indicates an existence of association between number of waters and rainfalls. There is a –0.37 rank correlation between Number of Water and Actual Rainfalls. Where as rank correlation between Number of Water and Weighted Rainfalls is –0.56. It depicts a strong association between the concerned variables and utility of weighted rainfall methodology.

Districts yield and season rainfalls

Table 9 shows coefficients of rank correlation between average yield of irrigated and un-irrigated areas of 35

Table 10. All Punjab Divisional models for wheat.

Comparison of all divisional models						
Divisions	**Sample points**	**Rain variables**	**R^2**	**MSE**	**Model sig.**	**Coeff. In model**
Gujranwala	4120	TotalRains	0.383	4.768	0.000	Insig
		WtRains	0.385	4.761	0.000	0.003
Rawalpindi	2016	TotalRains	0.454	3.189	0.000	0.001
		WtRains	0.454	3.189	0.000	0.009
Lahore	2988	TotalRains	0.326	5.263	0.000	Insig
		WtRains	0.326	5.263	0.000	Insig
Faislabad	2832	TotalRains	0.257	5.397	0.000	0.003
		WtRains	0.257	5.399	0.000	0.009
Sargodha	3090	TotalRains	0.458	3.773	0.000	0.003
		WtRains	0.458	3.774	0.000	0.012
Multan	4794	TotalRains	0.290	5.310	0.000	0.009
		WtRains	0.291	5.300	0.000	0.031
Bahawlpur	2622	TotalRains	0.319	4.925	0.000	0.019
		WtRains	0.321	4.913	0.000	0.066
DGKhan	2574	TotalRains	0.307	4.782	0.000	0.005
		WtRains	0.309	4.775	0.000	0.014

districts of Punjab for the year 2007 to 2008 (Table 9). As it was discussed earlier that irrigated area is comparatively less dependent on rainfalls as compared to un-irrigated area, the same is being depicted by the results shown in the Table 9. Rank coefficient of correlation for irrigated area, is improved from 0.10 to 0.23 when switching from actual to weighted rainfalls and same in case of un-irrigated area, it is significantly improved from 0.29 to 0.80.

Models for wheat projection

In this section the behavior of different divisional and provincial levels models was observed against total actual rainfalls and weighted rainfalls. For this purpose, data of wheat yield of 25036 plots from all the sample villages of the province from 2005 - 2006 to 2008 - 2009 were used. Two types of models were developed: one by using TotalRains as one of the 32 explanatory variables, second by using WtRains along with the same explanatory variables and taking wheat production of a plot as a response variable in both cases.

As response variable is continuous quantity (unit of response variable is yield in Kg/plot) and out of 32 explanatory variables 21 are categorical, therefore, 'Linear Regression Model' is the best choice for it (Montgomery et al., 1980). Firstly Divisional models are discussed (Table 10).

The commonalities in all the models are that they are all significant, in no case R^2 of WtRains is less than that of TotalRains. A decrement in MSE is more important to an increment in R^2 for the assessment of predictive performance of a model (Hahn, 1979).

In case of Lahore Division, the variation in the rainfalls was very minor so that both rainfall variables proved insignificant as shown in the last column of Table 10. Also in case of Gujranwala Division, TotalRains is insignificant but WtRains is significant. The last column of Table 11 also shows coefficient of both variables in their respective models. Coefficient of WtRains is mostly more than that of TotalRains, which shows that per unit change in the production of wheat is more than the per unit change in the WtRains as compared to TotalRains.

Same modeling patterns were used for provincial level models. Three models were developed: one for irrigated, second for un-irrigated and third by combining both types of areas (Table 11). Like all Divisional modes, all provincial models are also adequate as shown in the sixth column of Table 11. It is important to highlight that in all the provincial models, R^2 is maximum and MSE is minimum against WtRains as compared to TotalRains.

Table 11. Punjab level models for wheat.

Comparison of all provincial models						
Area	**Sample points**	**Rain variables**	**R^2**	**MSE**	**Model sig.**	**Coeff. In model**
Irrigated	22428	TotalRains	0.245	5.464	0.000	0.003
		WtRains	0.248	5.446	0.000	0.013
Un-irrigated	2608	TotalRains	0.358	3.094	0.000	0.003
		WtRains	0.365	3.065	0.000	0.004
Punjab	25036	TotalRains	0.384	5.250	0.000	0.003
		WtRains	0.386	5.234	0.000	0.013

The highest value of R^2 and the lowest value of MSE are obtained in case of Punjab model combining both types of areas and using WtRains as one of the explanatory variables along with other 32 explanatory variables. This model is finally selected for wheat projection. By applying different regression diagnostics, value of R^2 is improved to 0.443 and MSE to 4.289. The value of R^2 is directly proportional to the variation in regressor variables (Hahn, 1973). As in the study 21 regressor variables are categorical, so value of R^2 cannot be increased substantially from its current value.

CONCLUSIONS AND SUGGESTIONS

It is observed in the empirical study that in all the cases behavior of weighted rainfalls is better than that of total rainfalls and consequently better estimates of wheat are obtained using the concept of weighted rainfalls. The effort of weighted rainfalls is almost unprecedented in agricultural sciences for estimation of a crop and it is also an effort to convert a subjective approach into objective one regarding the importance of rainfalls during the period of wheat crop. By implementing the same technique for different crops of Rabi and Kharif seasons, weighted rainfall pattern can be determined for each crops.

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