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Changing Pattern of Weather Variables on Wheat Yield - A Statistical Analysis

Subhash Kumar, S. P. Singh and Mahesh Kumar*

Department of Statistics, Mathematics and Computer Application

Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar -848125

*Corresponding Author E-mail: mahesh_smca@yahoo.co.in

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ABSTRACT

This study examines the effect of climatic factor e.g. Temperature (Maximum and Minimum), Relative humidity (Morning and Evening), Evaporation and Rainfall variation on the yield of wheat in Samastipur district of Bihar by using statistical methods. The data of wheat yield of 29 Years (1984-2013) was taken from Department of Agricultural Economics, RAU, Pusa and Weather Variables (1984-2013) was taken from Agro-metrology Unit, RAU, Pusa. The time series information of yield and seasonal meteorological data e.g., Temperature (Max. and Min.), Relative humidity (Morning and Evening), Evaporation and Rainfall will have used trend to assess the using Mann Kendall Test and Theil Sen slope will have used to estimate changing pattern of weather variables on wheat yield. The resultant Mann-Kendall test statistic (S) indicates the presence of trend in weather factors like Temperature (Maximum and Minimum), Relative humidity (Morning and Evening), Evaporation and Rainfall and whether it is increasing or decreasing. Theil Sen slope estimator has been used to assess the magnitude of trend and percentage change in different variables has been calculated. Statistically significant trends are observed in all the variables. It is observed that wheat yield increases 29 % over the period (1984 - 2013). Negative trend is observed in maximum temperature and rainfall. Positive trend is observed in minimum temperature, humidity and evaporation.

Key word: *Mann-Kendall test, Theil Sen slope, Weather Variables, Temperature, Relative humidity, Evaporation, Rainfall*

INTRODUCTION

Evidently climate change is being realized in every walk of our life. Palpable impact is seen on growth and development, water use and productivity of major crops including wheat. Recently much attention has been given to the effects of climate change on agricultural output, because of the relevance of agriculture to the world economy, and the sensitivity of crop yields to climate conditions. Historically, much of the work on climate change impacts has focused on US outcomes, but recent work has increasingly studied developing countries, following predictions that the greatest short-term consequences of climate change may exist in the developing world.

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Climate change impacts on India can have far-reaching consequences, as well; India is the world's second largest producer of agricultural outputs, and any changes in production due to climate change could materially impact global agricultural imports and exports. Agriculture is the most vulnerable sector to climate change. Agriculture productivity is being affected by a number of factors of climatic change including rainfall pattern, temperature, relative humidity, evaporation, changes in sowing and harvesting dates, water availability, and evapo-transpiration and land suitability. The impact of climate change on agriculture is many folds including diminishing of agricultural output and shortening of growth period for crops. Countries lying in the tropical and sub-tropical regions would face callous results, whereas regions in the temperate zone would be on the beneficial side. Although the climate change in some areas of the world, particularly the areas located within the northern widths above 55 , will have positive effects on agricultural production[4], but the negative impacts of these changes will be so severe in hot and dry areas[9], so in developing countries the rise in temperature and the decrease in rainfall have been more severe and moreover the frequency and intensity of the occurrence of rare climatic phenomena (drought, heat, coldness and flood) will also be intensified[5]. Undoubtedly, any change in climatic condition will affect the agricultural production systems of the world. Mall and Singh[6] observed that small changes in the growing season temperature over the years appeared to be the key aspect of weather affecting yearly wheat yield fluctuations. Pathak *et al*[10]., concluded that the negative trends in solar radiation and an increase in minimum temperature, resulting in declining trends of potential yields of wheat in the Indo-Gangetic plains of India. Selvaraju[11] analyzed the relationship between Indian Summer Monsoon Rainfall (SMR) and food grain production in India. He found that the inter-annual variations are closely related. However, the magnitude of change in food grain production is smaller than the rainfall. Recent trends of a decline or stagnation in the yield of rice-wheat cropping system in Indo- Gangetic plain and north western India have raised serious concern about the regions food supply[1,10]. This trend clearly indicates the reduced factor of productivity in case of the rice-wheat cropping systems. These variations in trends of productivity indicate the effects of other biophysical and socio-economic components, which needs to be eliminated before embarking on assessing the impacts of climate change and its variability on growth and yield of crops. Easterling *et al*[3]., looked at studies that made quantitative projections of climate change impacts on food security. The first was that climate change would likely increase the number of people at risk of hunger compared with reference scenarios with no climate change. In 2006, the global estimate for the number of people under nourished was 820 million. This study aims to contribute to assessing how changing pattern of weather variables have affected the yields of major crops in India, over a 30-year time period from 1984-2014.

MATERIALS AND METHODS

The study was carried out in Samastipur district of Bihar in India. This is situated in Agro- climatic zone I (Northern West). The traditional agricultural practice is prevalent in this district. Then latitude and longitude is 25° 51′47.48″ N and 85° 46′48.04 0″ E respectively. It is situated at an elevation of about 52 m above mean sea level. The climate of the site is characterized by hot and humid summers and cold winters with an average rainfall of 1200 mm, 70 percent (941 mm) of which occurs during July -September and average temperature is maximum 36.6°C and minimum temperature is 7.7°C. Frequent droughts and floods are common in the region. Wheat productivity data is collected from Dept. of Agricultural Economics, DRPCAU Pusa, Samastipur, Bihar. We take data of wheat productivity and climatic variable from 1984-2014. We consider the average amount of wheat productivity in tonnes/hectare. The direct impact of climatic variables on wheat yield. The data regarding the climatic variables is collected data source from the Agrometeorology Unit, DRPCAU, Pusa, Samastipur Bihar. Following are the climatic factor and their units which are taken in this research**:** Maximum temperature (°C), Minimum Temperature (°C), Relative Humidity (morning) (%), Relative Humidity (evening) (%), Rainfall (mm), Evaporation (mm/m^2). Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic[7] and in hydrologic time series[15]. There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series[13]. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set (Blackwell). According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend. The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where i = 1,2, 3,…, n-1 and j = i+1, i+2, i+3,…,n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S[2]. The Mann-Kendall S Statistic is computed as follows: XLSTAT allows taking into account and removing the effect of autocorrelations. Sen's slope is computed if you request to take into account the autocorrelation(s).

The Mann-Kendall S Statistic is computed as follows

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n} \mathrm{sign}(T_j - T_i)\right]$$

Where

$X = (T_j - T_i)$

Sign (x) =1 for x > 0

Sign (x) = 0 for x =0

Sign (x) = −1 for x < 0.

Where T_j and T_i are the annual values in years' j and i, j > i, respectively[8]. If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than $_{\alpha/2}$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend[2]. For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows: E (S) = 0

The variance (σ^2) for the S-statistic is defined by:

$$\sigma^2 = \frac{(n(n-1)(2n+5) - \Sigma ti(i)(i-1)(2i=5)}{18}$$

In which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_s is calculated as follows:

$$Z_s = \begin{cases} \frac{s-1}{\sigma} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{s+1}{\sigma} & \text{for } S < 0. \end{cases}$$

The test statistic Zs is used a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H_0. If | Z_s| is greater than $Z_{\alpha/2}$, where α represents the chosen significance level (e.g.: 5% with Z 0.025 = 1.96) then the null hypothesis is invalid implying that the trend is significant. However, the slope of n pairs of data points was estimated using the Theil–Sen's estimator[12,14] is calculated as $Qi = (x_j - x_k) / (j - k)$ for i = 1…N

Where, x_j and x_k are data values at times j and k, (j>k) respectively. The median of these N values of Q_i is Sen's estimator of slope. If there is only one data in each time period, then N = n (n-1)/2 Where, n is the number of time periods. The median of the N estimated slopes is obtained in the usual way, i.e., the N values of Q_i are ranked by $Q_1 \le Q_2 \le \cdots \le Q_{N-1} \le Q_N$ and $Q_{(N+1)/2}$ if N is odd Sen's estimator = (1/2) $(Q_{N/2} + Q_{(N+2)/2})$ if N is even.

Change magnitude as percentage of mean

$$\%\text{ change } = \frac{\beta \times periodlength}{mean} \times 100$$

β = median slope (Theil Sen).

RESULTS AND DISCUSSION

Wheat yield

Fig 1 shows that trend of Wheat Yield (t/h) for the time period 1984-2013. The lowest wheat yield is observed in the year 1988-1989 (0.8 t/ha). which increased to (2.2 t/ha) during 1989-90.

There after not much variation during 1990-2002. Contrary to that, the yield was decreased to 1.1 t/ha in 2002-2003 and increased to 3.7 t/ha in 2012-2013 which was the highest.

Temperature

Fig 2 revealed that the variation in maximum temperature during 1984-2013 was not significant. Not much variation in minimum temperature was observed. Lowest minimum temperature (14^0C) was seen in year 1983-1984.

Relative Humidity

Fig 3 presented that the highest morning relative humidity was in year 1984-1985. However, during 1990-2013, steady behavior was observed. Lowest morning relative humidity was seen in year 1989-1990 (79%). Thereafter its value lies in the range of (80-85) %. Not much variation was observed in the evening relative humidity. A little bit variation was observed during 1989-1993 and after 1991 the range of variation was seen as 49-52%.

Evaporation

Fig 4 is the graph of 12 months of average data of evaporation, during 1984-2013. Graph of evaporation was seen as zig-zag type. Maximum variation was observed in this variable. Lowest value 2 mm/m^2 was observed during 1989 and highest (5 mm/m^2) in 2007-2008.

Total Rainfall

Fig 5 is the graph of 12 months of average data of total rainfall for the time period 1984-2013. Lowest rainfall was shown in year 1992-1993 (below 500 mm) and highest 2008-2009 (about 2500 mm). Graph of rainfall was seen as zig-zag type. Variation was not significant.

Seasonal Mann Kendall test Statistics, Theil Sen Slope estimator

The results of Mann-Kendall test on Wheat Yield (t/h), Maximum Temperature (^{O}C), Minimum Temperature (^{O}C), Relative Humidity Morning (%), Relative Humidity Evening (%), Total Rainfall (mm), Evaporation (mm/m^2) data are presented in Table 1. If p value is less than the significance level α (alpha) = 0.05, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates that there is no trend. On rejecting the null hypothesis, the result is said to be statistically significant. Table 1 indicates that the Null Hypothesis was rejected for only two variables Maximum Temperature (-899.0), and Total Rainfall (-438). When seasonal Mann Kendall Statistics value of yield was 435, Theil Sen slope value 0.021 then the percentage change in yield was 29.14. In maximum Temperature (^{O}C), when seasonal Mann Kendall Statistics value was -899, Theil Sen slope value -0.023 then the percentage change was -2.29. In minimum temperature (^{O}C), when seasonal Mann Kendall Statistics value of yield was 501, Theil Sen slope value 0.017 then the percentage change in yield was 2.58. When seasonal Mann Kendall Statistics value of relative humidity morning was 248, Theil Sen slope value was 0.038 then the percentage change in relative humidity morning was1.33. In relative humidity evening (%), when seasonal Mann Kendall Statistics value was 875, Theil Sen slope value 0.290 then the percentage change was 14.97. When seasonal Mann Kendall statistic value of total rainfall was - 438, Theil Sen slope value was -1.912 then the percentage change in total rainfall was -4.75. In evaporation, when seasonal Mann Kendall Statistics value was 1107, Theil Sen slope value 0.027 then the percentage change in evaporation was 23.56. Theil Sen slope value of Maximum Temperature (-0.023), and Total Rainfall (-1.912) and percentage change value of Maximum Temperature (-2.29), and Total Rainfall (-4.75) which is also negative trend is observed in Maximum temperature & rainfall and positive trend is observed in Minimum Temperature, Relative Humidity Morning, Relative Humidity Evening, and Evaporation. Change percentage has been computed by approximating it with a linear trend. That is change percentage equals median slope multiplied by the period length divided by the corresponding mean, expressed as percentage (Pc) followed by Yue and Hashino[15].

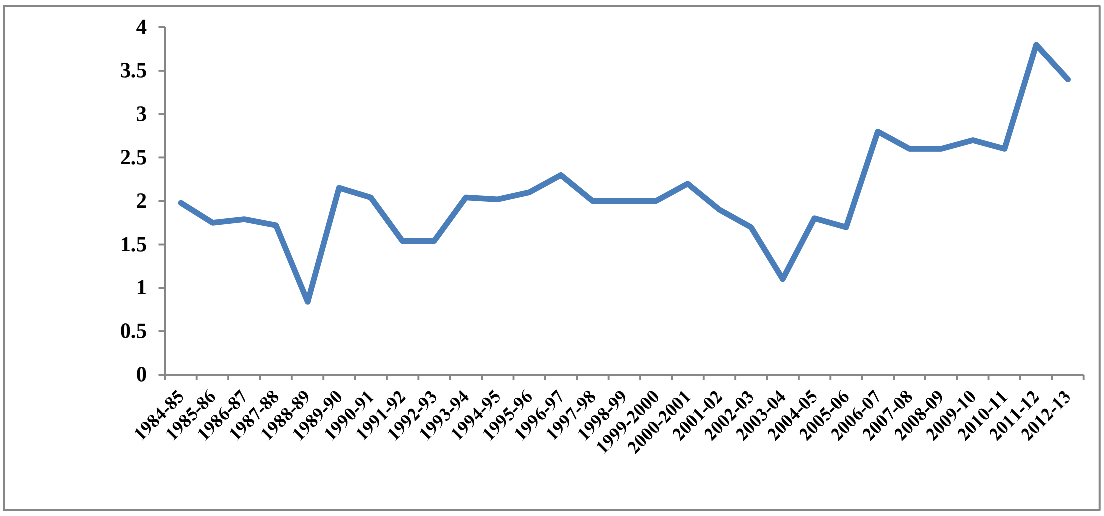

Fig. 1: Pattern of wheat yield (t/ha) for1984-2013

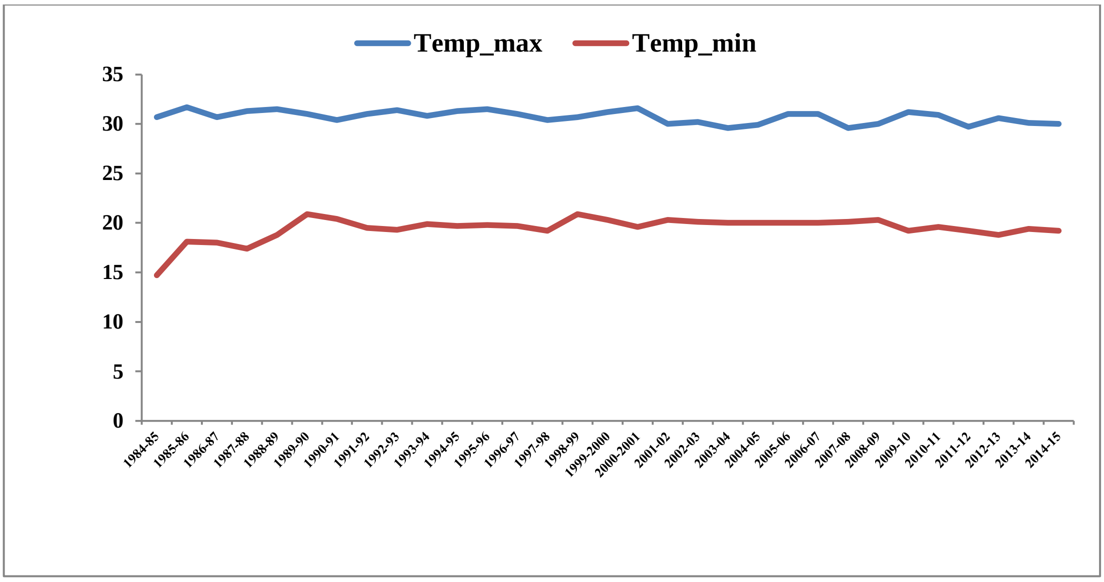

Fig. 2: Pattern of Temperature (Maximum and Minimum) (^{o}C) for 1984-2013

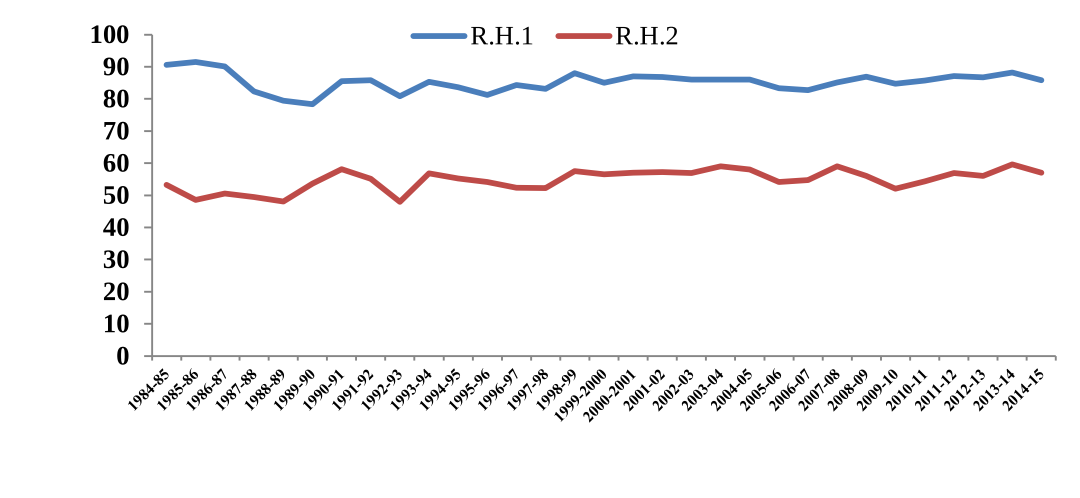

Fig. 3: Pattern of Relative Humidity (%) (Morning and Evening) for 1984-2013

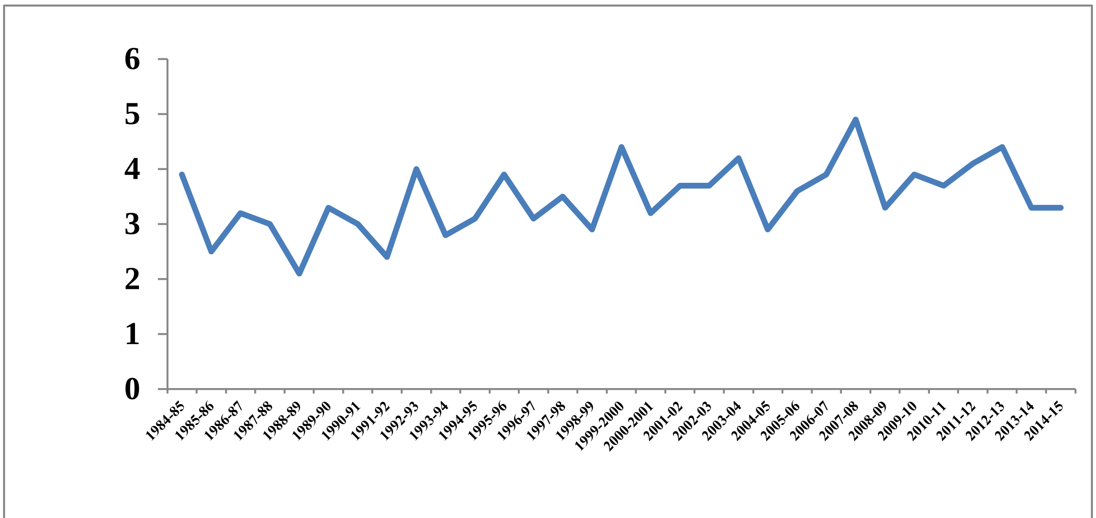

Fig. 4: Pattern of Evaporation (mm/m^2) for 1984-2013

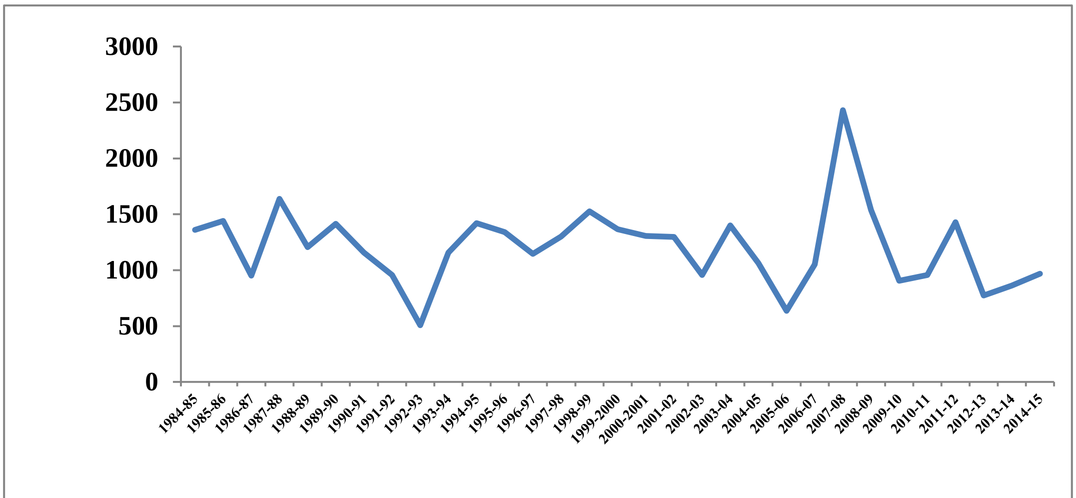

Fig. 5: Pattern of total rainfall (mm) for 1984-2013

Table 1 Result of seasonal Man Kendall test Statistics, Theil Sen Slope estimator test and % Change during 1984-2013

Variables	Mean	Seasonal MK Statistics	Theil Sen Slope (ß)	% Change
Yield (t/ha)	2.09	435 *	0.021	29.14
Max. Temp. (^{0}C)	30.53	-899 *	-0.023	-2.29
Min. Temp. (^{0}C)	19.41	501*	0.017	2.58
RH Morning (%)	84.30	248*	0.038	1.33
RH Evening (%)	58.19	875 *	0.290	14.97
Total Rainfall (mm)	1208.58	-438 *	-1.912	-4.75
Evaporation (mm/m^2)	3.45	1107 *	0.027	23.56

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