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Impact of Climate Variability and Its Related Disease Prevalence on the Yield of Winter Wheat (Triticum Aestivum Lam) in South East Ethiopia

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Abstract: Impacts of climate variability and disease prevalence on crop productivity (particularly wheat yield) are becoming major concern on their stable supply that affecting the livelihood of the farmers and consumers in South-East Ethiopia. The study was carried out with general objective to examine the effect of precipitation, temperature variation and disease prevalence on winter wheat (Triticum Aestivum Lam) for the last 20 years in Sinana farm of Oromia Seed Enterprise south east Ethiopia. Temperature and precipitation trends were evaluated using Sen's slope estimator and Mann-Kendall trend test methods. The Pearson's correlation coefficient was used to measure the strength of the association between crop yield and climatic variability. Predictor models on productivity status comprising disease prevalence associated to climate variability for 20 years were established. A1°C temperature rise in average seasonal maximum temperature above the optimum brought productivity reduction by 1.17% coefficient of determination R^2=0.428. Further, in 1°C temperature rise, the regression analysis of the productivity related to stem rust prevalence was subjected to a positive impact under Tmin, Tmax, RH, and seasonal RF with coefficient of determination R^2=0.756. On the other hand, yellow rust prevalence was positively correlated with minimum temperature, maximum temperature and average relative humidity, but it was negatively correlated with average seasonal temperature. The study concluded that the variability of climate elements has been exerting a huge impact on the quality and quantity of winter wheat.

Keywords: Climate Variability, Mann-Kendall, Sen's Slop, Stem Rust, Yellow Rust

1. Introduction

The effectiveness of temperature and rainfall on wheat production and yield is a significant tool of agronomy. The influences of rainfall and temperature on soil water and the grain production of winter wheat (*Triticum aestivum L.*), is important to ensure the sustainability of food production [1]. Agronomic and economic studies also make frequent use of temperature and precipitation data to assist in explaining patterns in expected crop yields or crop production risk (e.g., variability in crop yield, susceptibility of yields to droughts, heat waves, frosted) (Robertson et al, 2013) [2]. A common approach in modeling temperature or heat effects on crop yield is to use average air temperatures over a specified period. Moreover, the crops are, as a matter of fact, highly sensitive to seasonal rains, temperature and relative humidity occurring during the sowing, germination, vegetative, flowering, and seed-filling and harvesting periods. For instance, the average minimum and maximum temperature needed for germination is 0°C and 20°C-22°C respectively [3]. Besides, precipitation is one of the influential climate elements in determining crop productivity. Ethiopian agriculture is mostly rain-fed, whereas inter-annual and seasonal rainfall variability is high and droughts are frequent in many parts of the country [20]. Its variability has historically been a major cause of food insecurity and famines in the country. Surprisingly, however, the relationships between rainfall variability and fluctuations in agricultural production at regional and sub-regional scales have not been studied in detail [4]. Excessive or deficit amount of water could retard crop growth and ultimately lower crop yield. For instance, under particular climatic conditions, wheat requires different amounts of water during its stage of growth. Initially during seedling, sprouting and early growth, crop uses water at the relatively slow rate. As growth proceeds, this rate will increase to reach a maximum and then declining toward maturity [5]. However, the effect of rainfall variability on wheat production varies with types of varieties grown, types and properties of soils and climatic conditions of a given area [6]. Water deficits during grain filling not only reduce carbon assimilation rates, but increase canopy temperature via reduced transpiration rates and canopy senescence via accelerated leaf senescence [7]. Therefore, change in temperature and rainfall would change phonological requirements of future crops will, in fact, likely be the first factor to explore in explaining differences in yields [8]. Rainfall variability usually results in reduction of 20% production and 25% raise in poverty rates in Ethiopia [9].

Impacts of climate variability and disease prevalence on crop productivity (particularly wheat yield) are becoming major concern on their stable supply that affecting the livelihood of the farmers and consumers in South-East Ethiopia. Most disease on wheat are Stem and Yellow Rust Prevalence in the major productive area of Ethiopia highlands [25]. The study was carried out with general objective to investigate the effect of precipitation, temperature variation, disease prevalence on winter wheat (Triticum Aestivum Lam) for the last 20 years in Sinana farm of Oromia Seed Enterprise south east Ethiopia. The long-term data from the Enterprise such as monthly precipitation of each year, seasonal precipitation, mean minimum temperature, mean maximum temperature and disease prevalence of strip rust and stem rust on winter wheat were collected, classified, arranged, and coded for this research work. The research area is located in the Oromia Regional State at 07° 07' N and 40°10' E and 2400 meters above sea level in South East Ethiopia where wheat yield widely practiced. The study area with its surrounding is characterized by bimodal rainfall forming two growing seasons in a year. The main season locally called 'Bonaa' means Winter (extends from August to December), and the other season called 'Ganna' meaning Summer (extends from March to July). The annual rainfall ranges from 750 to 1000 mm (average 776.29 mm). The main growing season receives 270 to 550 mm rainfall, while the short growing season receives from 250 to 560 mm. The average annual maximum temperature was 21°C and minimum temperature is 9°C. The soil type is dominated by vertisols and slightly acidic [10].

2. Data Method

Climate variables data including total monthly and seasonal rainfall (mm) of each year, mean minimum temperature, mean maximum temperature, and average monthly temperature and average relative humidity of the cropping seasons from 1996-2016 was collected from the Ethiopia Meteorological Service for this study purpose. Data of winter wheat yield, diseases prevalence of strip rust and stem rust were collected from Oromia Seed Enterprise of Sinana in same period to the meteorological data. The climate data and winter wheat productivity is plotted in figure 1, disease prevalence of yellow (strip) and stem rust is plotted in figure 4.

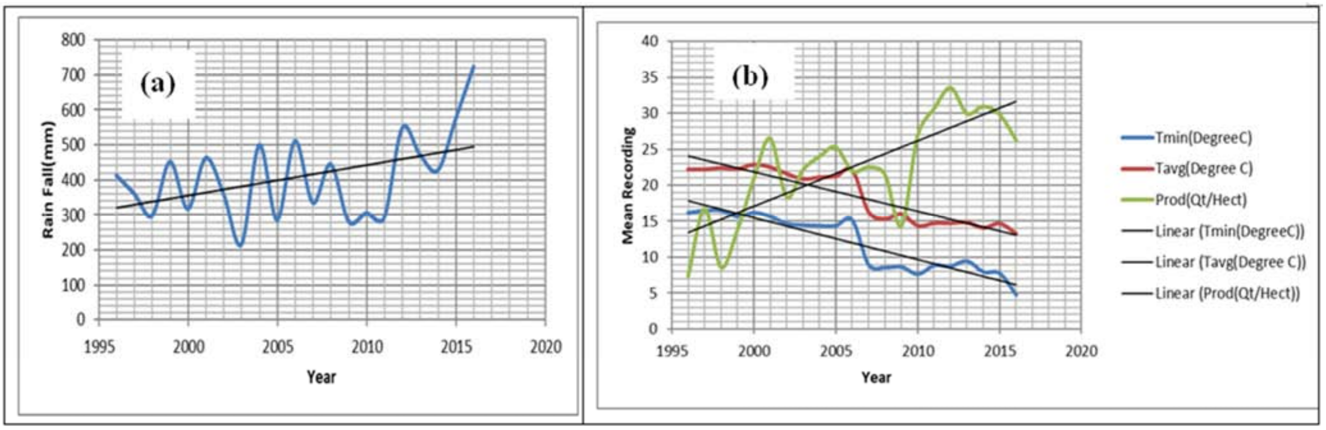

Figure 1. *(a) Patterns of Seasonal rainfall (left) from Ethiopian Meteorolgy Data Log; (b) climate data and Productivity in Sinana farm of Oromia Seed Enterprise (Qt/hect) from.*

The traind of figure 1 is quantified by Sen's slope method. Sen's slope is another index to quantify the trend using the nonparametric procedure developed by different research works [21-23]. (Forkel et al; Gocic and Trajkovic; 2013; Yue, and Wang, 2004). The slope of the trend is commonly computed by equation (1).

$$Q_i = \frac{X_j - X_k}{j - k} \quad (1)$$

Where i=1, 2, 3, N, X_j and X_k are the data at the time of j and k (j>k).

The cumulative observed change ΔY in seasonal wheat productivity as result of climate variables or anomalies has been predicted by a linear model represented by equation (2).

$$\Delta Y = cons + \alpha \Delta P_{pt} + \beta \Delta T_{\min} + \gamma \Delta T_{\max} \quad (2)$$

Where α, β and γ are the correlation coefficients of the precipitation, minimum temperature and maximum temperature during the season, respectively. They are separately calculated from Pearson's correlation coefficient γ in equation (3) determining the correlation between the climate elements and the seasonal wheat yield.

$$r = \frac{\sum_{i=1}^{N} (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_{i=1}^{N} (x - \bar{x})^2 (y - \bar{y})^2}} \quad (3)$$

The ΔP_{pr}, $\Delta T_{\min}$ and $\Delta T_{\max}$ in equation (2) are the observed changes.

2.1. Sen's Slop Method

The seasonal analysis of maximum and minimum temperatures and precipitation has been investigated using Sen's Slope and Man-Kendall [11] approaches as described in figure 2. Mann-Kendall trend estimation at Sinana- Farm assuming that there are fluctuation tendencies in maximum and minimum temperature reading the last 20 years throughout growing season as indicated in table 1.

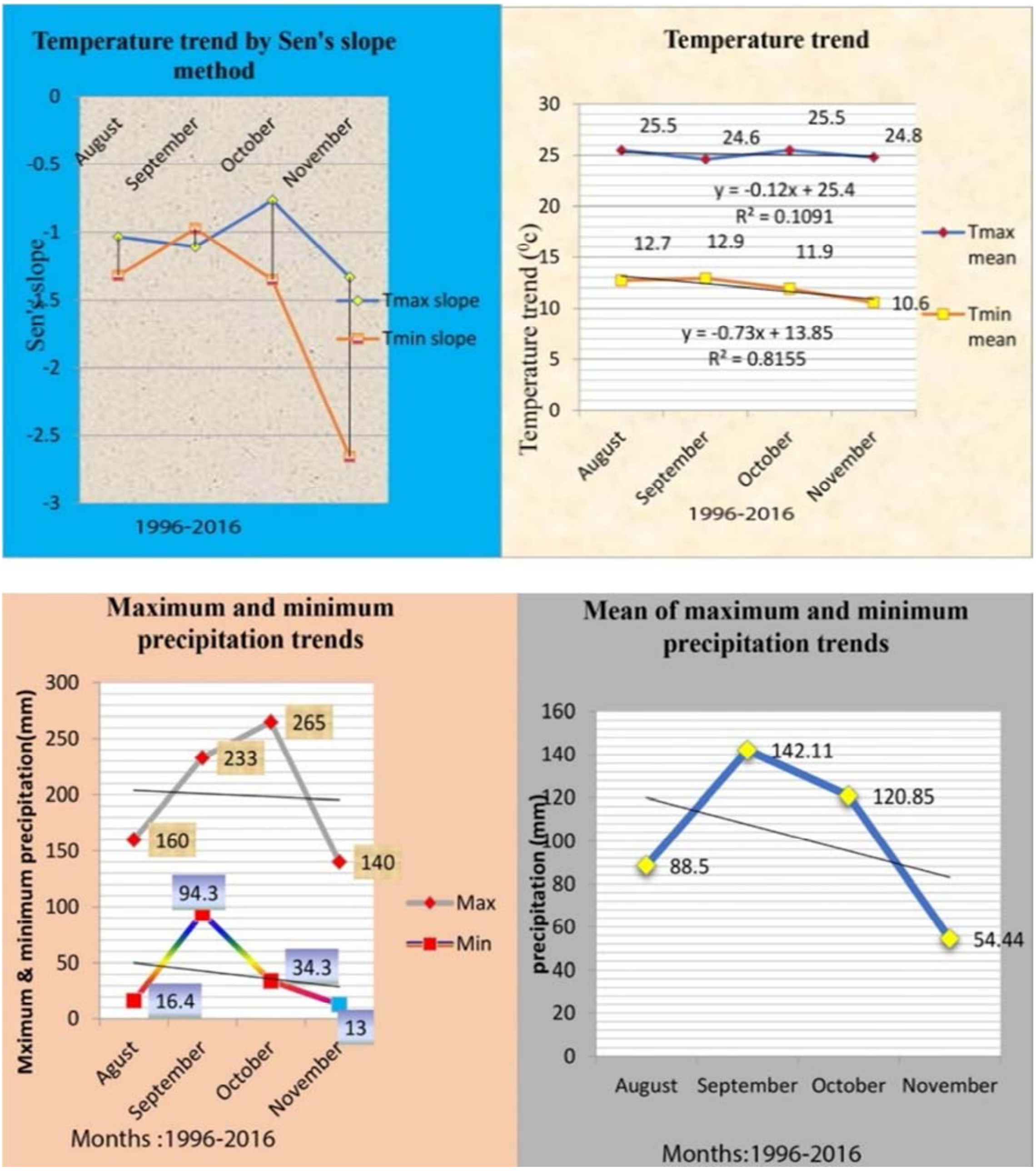

Figure 2. *Sen's slope, mean of maximum, minimum temperature Trend analysis of monthly precipitation.*

Table 1. *Trend analysis of monthly Sen's slope and mean maximum and minimum temperature at Sinana Farm.*

Month		Sen's Slope (°C)/season	Mann-Kendall	P-value	Confidence interval (CI)	Linear trend
August	Tmax	-1.035	-0.316*	0.01	-1.795 to -0.274	48.881
	Tmin	-1.323	-0.468**	0.002	-2.091 to 0.555	39.356
September	Tmax	-1.109	-0.408*	0.019	-2.014 to -0.204	49.746
	Tmin	-0.974	-0.185	0.035	-1.874 to -0.075	35.132
October	Tmax	-0.768	-0.504**	0.006	-1.291 to -0.244	42.065
	Tmin	-1.354	-0.524**	0.000	-2.007 to 0.70	38.685
November	Tmax	-1.335	-0.603**	0.000	-1.99 to -0.68	55.588
	Tmin	-2.654	-0.398*	0.007	-1.436 to -0.256	31.498

Furthermore, the minimum temperatures recorded in the September are statistically significant. As statistical description further proves, average minimum temperatures registered in the past 20 years in the month of November, August, October and September were 3.4°C, 5.9°C, 6.1°C, 6.9°C respectively. The minimum temperature occurred in the month of November is considered as a critical period in which Winter wheat in the grain filling stage. Traditional rain fed wheat (*Triticum aestivum L.*) production areas are best described in a zone with 350 mm or more precipitation and mean minimum temperatures of 6°C to 11°C [5] during the wettest quarter. Similarly, the average maximum temperature over the last 20 years in the month of September, November, August and October were also 29.6°C, 30.3°C, 31°C and 33.3°C. On the other hand, there was high significance of maximum temperature both in October and November. The remaining two months are less significant by comparing through their p values described in table 2. The average maximum temperature for optimum growth of winter wheat lies in the range of 20°C and 25°C [5]. However, the increase in temperature and reduction in humidity enhances the transpiration rate that led to less water availability for photosynthesis in plant tissues, causing yield reduction [12]. In the Sen's slope method, both maximum and minimum temperature trends are decreasing as illustrated in the table 1.

Table 2. *Trends of seasonal, maximum and minimum temperatures.*

Parameter	Sen's slope (°C)	Mann-Kendall	P-value	Confidence interval (CI)	Linear Trend
Tmax	-1.259	-0.492	0.002	-1.992 to -0.525	54.154
Tmin	-1.133	-0.481	0.004	-1.846 to -0.419	36.101

Trend analysis of monthly and seasonal rainfall for maximum, minimum and mean data from August to November for 20 years (1996-2016) has been done in figure 2, tables 3 and 4. Mann-Kendall, Sen's Slope Estimator and Regression analysis has been instrumental for the determination of the trend and magnitude of trend. As Mann-Kendall statistical test, there was an increasing precipitation trend from August month to September. There was also variability of rainfall over each growing seasons. On the hand, Sen's slope proves that the precipitation trends were declining from September to November throughout the 20 years. Further Sen's Slop test evidenced that there was a positive sign increment not statistically significant in seasonal precipitation. The rain fall trends were generally variable from month to month in the growing season in the area. However, this variability was not statistically significant throughout the growing months. This erratic variation in all months can lead to crop moisture stress if production planning is not properly planned [13].

Table 3. *Trend analysis of monthly precipitation (mm) at Sinana weather stations from (1996 -2016).*

Month	Sen's slope (mm/season)	Mann-Kendall	P-value	Confidence interval (C. I)	Linear Trend
August	0.055	0.234	0.000	9.346 - 25.939	17.642
September	0.084	0.305	0.053	-0.17 - 0.001	34.502
October	0.056	0.257	0.036	0.004 - 0.109	16.697
November	0.036	0.438	0.011	0.027 - 0.185	14.736

From Mann-Kendall trend, there is variability of precipitation throughout the growing season in each growing seasons. Trend of precipitation (mm) of Sen's slope (mm/season), Mann-Kendall, P- Value, Confidence interval (C. I) linear trend at site station are shown in Table 4. The Sen's slope was indicating a positive sign in seasonal precipitation, the incremental trends of precipitation is not highly significant in the analysis.

Table 4. *Trend analysis of seasonal precipitation (mm) at Sinana weather stations.*

Station	Sen's slope (mm/season	Mann-Kendall	P-value	Confidence interval (CI)	Linear Trend
Sinana	0.032	0.36*	0.022	0.01 - 0.64	9.63

As table 5 describes, the crop growing season from (1996-2016) was exhibiting a high total seasonal precipitation variability with the minimum value of 281.40 mm and the maximum value of 724.00 mm rain fall. This scenario signaled high variability among the seasonal total rainfalls per year. On the other hand, maximum precipitation scored in each growing season of 20 years back was increasing trends from August to October and then it was accompanied by a decline move from October to November. The trend pattern was almost in line with [14] who stated that the trend of precipitation was variable from season to season in Sinana woreda.

Table 5. *Descriptive statistics of monthly precipitation at Sinana weather stations.*

		August rain fall (mm)	September rain fall (mm)	October rain fall (mm)	November rain fall (mm)	Total seasonal rain fall (mm)
Mean		88.5	142.11	120.85	54.44	405.91
Std. Deviation		38.49	36.73	58.96	36.94	98.65
Minimum		16.4	94.30	34.30	13	281.40
Maximum		160	233	265	140	724
	25%	62.55	113.3	72	24.9	335.2
Percentiles	50%	90.9	134	128.8	45	379
	75%	112.25	172.3	157.2	79.15	453
C.V. (%)		43.49	25.84	48.79	67.84	24.3

Trend productivity of winter wheat in the farm over the last 20 years as noticed in figure 1 (b) was accompanied by unstable up-down moves. This was increment productivity rate in the interval between 1999 and 2012. However, from the year 1998 to 2000; 2007 to 2011, the productivity trends were observing deep recessions below the average impacted by erratically precipitation coverage in the study area. Therefore, the amount of precipitation at early sows to germination period and grain filling stage of winter wheat (Triticum sativum Lam) was declining resulting productive rate reduction.

2.2. Trend Analysis of Productivity of Winter Wheat

From the data research in figure 1, the productivity of winter wheat in the farm over the last 20 years showed irregularity output. From 1998 to 2003 for consecutive four years, the productivity was in line with incremental rate from year to year. In 2002, it was declined from normal incremental trends. From 2003 to 2005, there was a gradual increase. In 2013, 2006 and 2007, similar productivity closer to 22Qt/ha was harvested. Within 20 years' productivity history in Farm, the highest productivity was achieved in 2012. The least productivity was registered in 1996 even though there was relatively higher rainy season. On the other hand, in 2014, the rain level was 379 mm with 29.83 Qt/ha achievement.

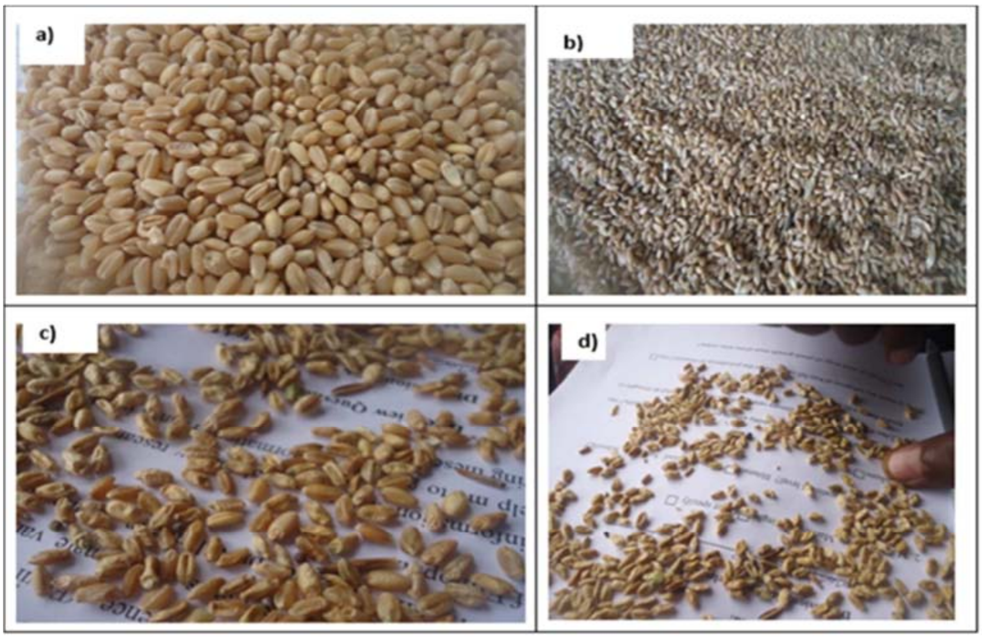

Figure 3. *The impact of climate variability on wheat seed (winter) sample at Sinana farm: a) health seed b) rain fall and temperature impact on wheat seed c) wheat seed slightly affected by Frost d) wheat seed severely affected by frost.*

According to the data trends, the amount of precipitation at early sowing to germination period and grain filling stage were declined performance resulting in productivity reduction. Exclusively August and mid-November are the critical period crop need optimum precipitation. Over the last 20 years, except in 2010-2016, the productivity was subjected to an uneven distribution of precipitation. In August, the precipitation was very low and an erratic nature affecting the beginning of sowing to germination period. Besides, in November, there was no enough precipitation to nourish the crops perform successfully physiological activities. The climate variability affecting the status of winter wheat at the study area are pictured and compared with the healthy one in figure 3.

2.3. Diseases Prevalence

These data had been recorded by the farm every year by estimating percentage of leaf area affected through Modified Cobb Scale [15, 16] and the infection types had been also recorded every year periodically at various stages of plant growth. Finally, they were converted to coefficient of infection (C. I) using the method employed by [16]. Diseases prevalence has been assessed by sampling techniques of diagonally crossing each blocks of the farm every year by experts of farm. Combining of data series and simulation models can be a valuable approach in projecting the future climate change impact on wheat diseases. It is particularly important to collect long-term data sets for weather parameters, crop development, and disease prevalence to be able to develop and validate linked 'climate-crop- disease' models [17-19]. The disease prevalence of yellow and stem rust was graphed by percentage as shown in figure 4.

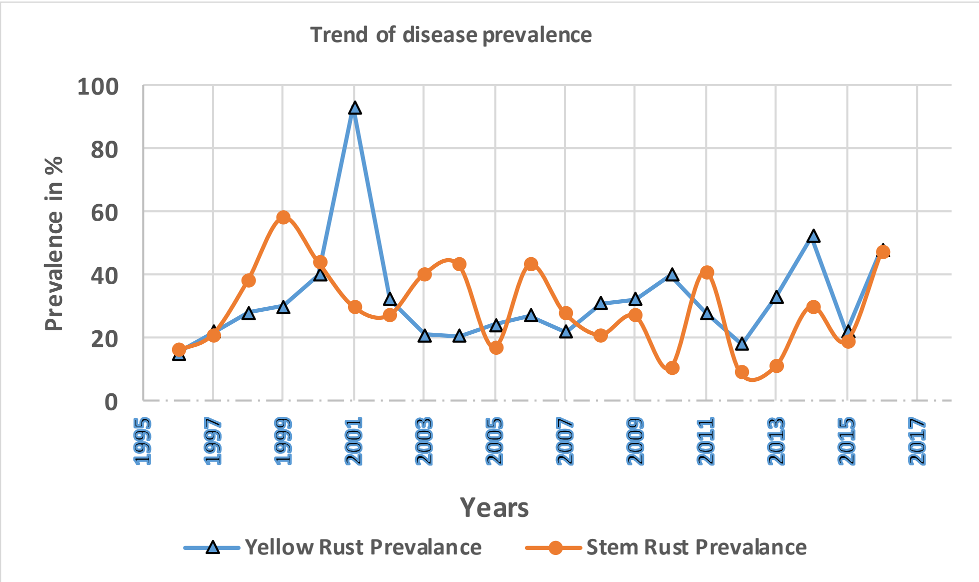

Figure 4. *Trends of diseases prevalence at Sinana farm (1996-2016).*

3. Result and Discussion

3.1. Correlation Analysis of Productivity with Variability of Climate Elements

The productivity had strong negative correlation by season (r=-0.63, -0.62, 0.61 to -0.43; P ≤ 0.01) described in table 6. This scenario proves that the productivity decreased as the amount of climate elements fluctuates from optimum level. However, there was no significant effects from relative humidity on the yield as r=0.25.

Table 6. *Pearson's correlation coefficients between winter wheat productivity and climate elements.*

Variability of climate elements	Basis of analysis	Winter wheat productivity (Qt/ha)
Minimum temperature	Season	-0.61**
Maximum temperature	Season	-0.62**
Average temperature	Season	-0.63**
Average seasonal HR	Season	0.25
Total rainfall	Season	-0.43*

** Correlation is highly significant at 0.01 * Correlation is significant at 0.05

3.2. Correlation between Stem Rust Prevalence with Climate Elements

Stem rust prevalence was getting increasing as seen figure 5 over the last years as positively correlated with minimum temperature (r=0.40), maximum temperature (r=0.51), average seasonal temperature (r=0.46), seasonal precipitation (r=0.14) and relative humidity (r=0.15), respectively.

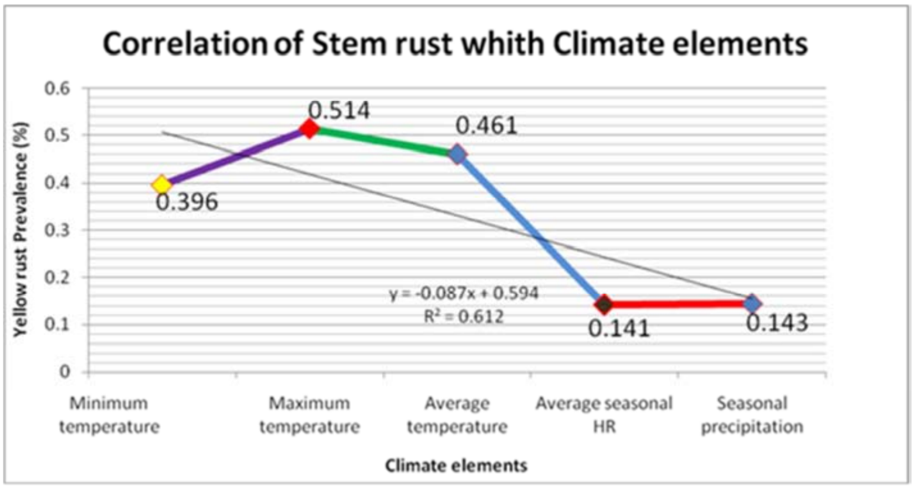

Figure 5. *Correlation coefficients of stem rust with climate elements.*

3.3. Correlation Between Yellow Rust Prevalence with Climate Elements

Yellow rust prevalence was rising over the last 20 years as positively correlated with minimum temperature (r=0.29), maximum temperature (r=0.21) and average relative humidity (r=0.15) described in figure 6. In contrary, it was negatively correlated with average seasonal temperature (r=-0.25) and seasonal precipitation (r=-0.26).

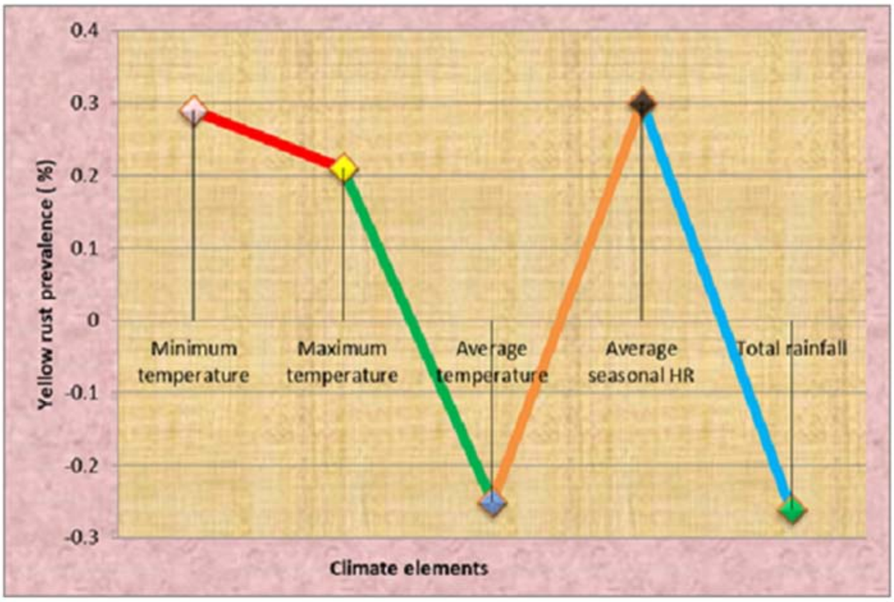

Figure 6. *Correlation between climate elements with yellow rust prevalence.*

3.4. Multiple Regression Analysis with Climate Elements

The regression analysis on the productivity is a positive effect of seasonal minimum temperature and total seasonal precipitation as observed in the model equation 4. On the other hand, there was strong negative correlation relationship between seasonal maximum temperature and the total productivity. A 1°C temperature rise in average seasonal maximum temperature above the optimum brought productivity reduction by 1.17%. The coefficient of determination R^2 for the predictive model over the seasonal elements is about 0.428.

$$Y = -46.97 + 0.44T_{\min} - 1.17T_{\max} + 0.51RF \tag{4}$$

3.5. Multiple Regression Analysis of Disease Data

The increment in precipitation has brought stem rust prevalence rising as it is indicated in predictive model equation 5.

In 1°C temperature rise, the regression analysis of the productivity related to stem rust prevalence was subjected to a positive impact under T_{min}, T_{max}, RH, and seasonal RF, respectively with R^2=0.756.

The outcome of the analysis has similar outcome with work of Paterson (2010), who stated that an increment in climate elements resulted in stem rust prevalence at large when diseases triangles are fulfilled.

$$Y = -25 + 0.7T_{\min} + 0.82T_{\max} + 0.40RH + 0.17RF \quad (5)$$

On a similar work, maximum temperature, average relative humidity, total seasonal precipitations brought positive impact on wheat yellow rust prevalence described in the model equation (6) with R^2=0.188. On the contrary, there was a negative effect of minimum temperature on the prevalence of yellow rust.

$$Y = 3.135 - 1.748T_{\min} + 1.203T_{\max} + 0.154RH + 0.018RF \quad (6)$$

4. Conclusion

The study revealed that high variability of monthly and total seasonal precipitation in the winter wheat production has been fluctuating resulted in productivity reduction in Sinana Farm and its surrounding locations. Exclusively, the lowered precipitation in August at early wheat germination stage and in November at grain filling stage is one of the challenges in the area. Monthly precipitation was mostly inclined to decreasing trends throughout the last 20 years.

The productivity was strong negatively correlated to average seasonal temperature with r=-0.63, maximum temperature with r=-0.61 and minimum temperature with r=-0.43. The impacts are statically significant proving that their P values extremely less than 0.01. Stem rust prevalence was also positively correlated with minimum temperature (r=0.40), maximum temperature (r=0.51), average seasonal temperature (r=0.46), seasonal precipitation (r=0.14) and relative humidity (r=0.15). Yellow rust prevalence was also positively correlated with minimum temperature (r=0.29), maximum temperature (r=0.21) and average relative humidity (r=0.15). In contrary, it was negatively correlated with average seasonal temperature (r=-0.25) and seasonal precipitation (r=-0.26). The regression analysis for proved that there was a positive effect of total seasonal precipitation, total minimum temperature, maximum temperature, average seasonal relative humidity and total seasonal precipitation on stem rust prevalence. The study concluded that the variability of climate elements has been exerting a huge impact on the quality and quantity of winter wheat. Further, instability on climate variability has induced stem rust and yellow rust disease prevalence adversely affecting the wheat production in area.
Combatting the effect of unstable climate variability and disease prevalence on the wheat production, the research finding is to propose some strategies as follow

1) Adjusting the sowing time can overcome the shortage, fluctuation of precipitation and variability of temperature.
2) Application of improved winter wheat varieties that capable to withstand drought, frost and diseases.
3) Designing a means for administering plant nutrient spray mechanism when the crop is subjected to erratic precipitation and temperature variability.
4) Employing short life cycle wheat varieties is better recommended.
5) Crop rotation in the area plays a vital role in reducing diseases prevalence by disturbing life cycle of fungal diseases
6) Using plant nutrients that sprayed to winter wheat varieties at stage of crop subjected to shortage of precipitation and temperature variability by helping in reducing/regulating rate of evaporation and transpiration from the living plants by the mechanism of reflecting solar radiation.
7) Mapping of varieties to the recommended ecology based up on soil type and topology.

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