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CLIMATE CHANGE AND TEA YIELD OVER MURANG'A COUNTY: BASIC REGRESSION APPROACH

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ABSTRACT

Tea is currently the major cash crop in Kenya. Tea production plays an important role in the export market, employment sector and also is a source of revenue for the country. The need to predict the effect of climate change on tea production prompted this statistical investigation to determine tea crop response to climate variables. A statistical model was trained on historical tea yield data and corresponding minimum temperature, maximum temperature and rainfall examined over Murang'a County. Scatter plot for climate variables were generated and correlation analysis between these variables and tea production variables were carried out. A multiple linear model was developed and residual plot was used to verify the model where regression assumptions were explained. Correlation analysis gave positive correlation on tea yield versus the other variables under study, where maximum temperature gave the highest positive correlation, and rainfall gave weak positive correlations. The study points out the possibility of increased yield of tea corresponding to changes in climate variables possibly up to optimum amounts beyond which the changes in temperature may negatively affect the yields. The study recommends integrated modelling to include many other factors that can affect the yield of tea over the area of study.

KEYWORDS: Climate Change, Yield & Tea, Murang'a

1. INTRODUCTION

1.1 Background of the Study

Agricultural sector is among the key drivers to economic growth in Kenya (D'Alessandro et al.,2015). Contributing 24.5% of the total GDP valued at 741 billion Kenya shillings as observed in the year 2011. On average, an estimated 27% of the overall GDP is contributed by Agricultural sector. It's also the main source of employment according employing approximately 75% of the labor force in the country with more than 80,000 people working on the estate and about 3.2 million people earning their livelihood from the sector (D'Alessandro et al.,2015).

According to (Conway et al., 2005) the impact of climate variability is more pronounced where people are highly dependent on natural resources for their livelihood. This is corroborated by Stocker *et al.,(*2013) which observes changes in the frequency and intensity of weather and climate events negatively impacting human and natural systems much more than gradual changes in the mean condition. The stress of climate change on tea has also been documented in a study by Han & Ahammed (2018) and Ahmed et al., (2018) with disruption of ecological processes associated with tea noted as a key impact due to increasing climate variability. This impact on yields has been observed in many countries including India (Dutta, 2014).

In Sri Lanka, tea cultivations at low and mid elevations are more vulnerable to climate variation than those at high elevations with 22°cbeing the optimal temperature for tea cultivation Wijeratne (2007). It has also been observed that rainfall reduction by 100mm could reduce the yield by 30kg to 80kg per ha. There is however variations in the optimal rainfall for tea production in some regions from 223 to 417 mm per month. In general, rising temperature and diminishing rainfall has a negative impact on tea yield in many tea growing zones except in wet upcountry areas.

In Kenya; Cheserek, Elbehri & Bore (2015) investigated the link between climate variables and tea production in the recent past in Kenya. This study linked tea yield to temperature, rainfall and soil water deficit. The study area was Timbilil tea estate in Kericho and Magura tea estate in Sotik. The results of the investigation revealed that warm temperature can be conducive for tea production in the presence of non-inhibitive soil moisture. With a significant relationship between yield and mean air temperatures ($p<= 0.05$, $n=270$, $r^2=0.928$) in non-limiting soil moisture, temperature increase can be conducive to tea production to optimum climate conditions beyond which negative impact can be felt on tea yield. Studies by Sitienei et al., (2017) would also predict loss of tea yields in Nandi East Sub-County associated with climate change.

In Murang'a County; Tea growing areas include the Aberdare region with an estimated output of up to two-third of the tea production in central Kenya (Leshamta, 2017). While temperature and rainfall are paramount for tea production, their possible variation and impact on tea yield have not received more desired research focus prompting this investigation. Multivariate regression method can be used for Prediction of crop yields in a changing climate as explained by Juma & Beru (2021). This study applied this criterion to estimate the crop yields over the area of study.

1.3 Objective of the Study

1.3.1 General Objective

The main objective of this study was to apply regression methods in determining the relationship between climate variables and tea yield over the area of study. This was achieved through the following specific activities:

1.3.2 Specific objective

- To investigate the relationship between maximum, minimum temperature and rainfall with tea yield over Murang'a County
- Specify a predictive regression Model using temperature and rainfall variables

CHAPTER TWO: METHODOLOGY

2.0 Data and Methods

2.1 Data Source

Secondary data was used. Monthly temperature and rainfall data spanning from 2014 to 2018 was obtained from Kenya meteorological department while monthly data of tea production was obtained from Gatunguru tea factory which is located in Murang'a County, Mathioya Sub County.

2.2 Analysis

R programming Statistical software and SPSS were used for analyses.

2.2.1 Correlation analysis

The study employed the Pearson correlation coefficient to measures the strength of association between variables under investigation. The Pearson's correlation coefficient is given by;

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where n=no of pair of scores

$\sum xy$ = sum of product of paired scores

$\sum x$= sum of x scores

$\sum y$=sum of y scores

$\sum x^2$= sum of squired x score

$\sum y^2$= sum of squired y score

Degree of freedom is given by n-1

To test whether the correlation is significant, the null hypothesis that the correlation is zero and the alternative hypothesis that the correlation is nonzero will be assumed. The student t-statistic that was used which is given by;

$$t = r\sqrt{\frac{n-2}{1-r^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

Where r is correlation and n is the sample size.

2.2.2 Regression Analysis

Our study had four variables; Temperature (minimum and maximum) (X_1): Rainfall(X_2): Tea yield (Y)X_1 and X_2 independent variable while Y is the dependent variable. The data was imported into R programming software where regression analysis was carried out in order to get coefficients $ßo$, $ß_1$and$ß_2$. These values were fitted in a multiple regression model of the form;

$$Y = ßo + ß_1X_1 + ß_2X_2 + \cdots + ßκXκ + ε \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

ßo is a constant, $ß_1$,$ß_2$…ßκ are the coefficients and χ's are the predictors (independent variable) while Y is the dependent variable or the value of tea produced ε is the error factor.

The least square of a multiple regression is given by

$$ß = (x'x)^{-1}x'y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iv)$$

Where x' is the transpose of x and$(x'x)^{-1}$: is the inverse of $(x'x)$

Pearson's product-moment correlation data was generated from the variables utilizing the alternative hypothesis (true correlation is not equal to 0) at 95 percent confidence interval giving sample correlation coefficients among the variables. Scatter plots for individual climate variables were generated against the tea yield and regression model specified.

The regression model for predicting tea yield was arrived at via a series of enhancing steps where the initial step entailed all climate variables specified in the data file. (Formula = tea_prod ~ min_temp + max_temp + rainfall, data = file). In this step, it was observed that rainfall variable has a p-value greater than 0.05 and hence not statistically significant in the model at 95% confidence level. The second step was a repeat of the first one excluding the non-significant variable in the data file. A model that entailed the statistically significant climate variables was specified and adopted.

The third step entailed plotting the model residuals with keen interest on the normal Q-Q plot to detect the outliers. Where outliers were detected, the model had to be "re-built" without outliers. The final outlier-less model was specified with the following key assumptions namely:

Homoscedasticity of residual based on equal variance; Normality of residual; Leverage based on distance of plots to the center and the cook's distance; Positive variance and non-perfect multicollinearity.

RESULTS AND DISCUSSIONS

3.1. Results of correlation Analysis

The correction between minimum temperature versus tea yield was observed to be positively

Linear at r =0.783438 while that between maximum temperature versus tea yield depicted a strong linear relationship at r= 0.7586485. However, a weak positive linear relationship was observed between rainfall amount and tea yield at r = 0.36.

3.2. Scatter plots of climate variables

Figures 1 to 3 shows the scatter plots between the three climate variables and tea production (yield) respectively. Positive linearity is observable across all the graphical representations with specific focus to the maximum temperature plot where it can be seen that as temperature increases, tea yield increase but at a very high temperature the yield starts decreasing. The optimum temperature is approximately 24 to 25 degrees Celsius as seen from figure 2 below.

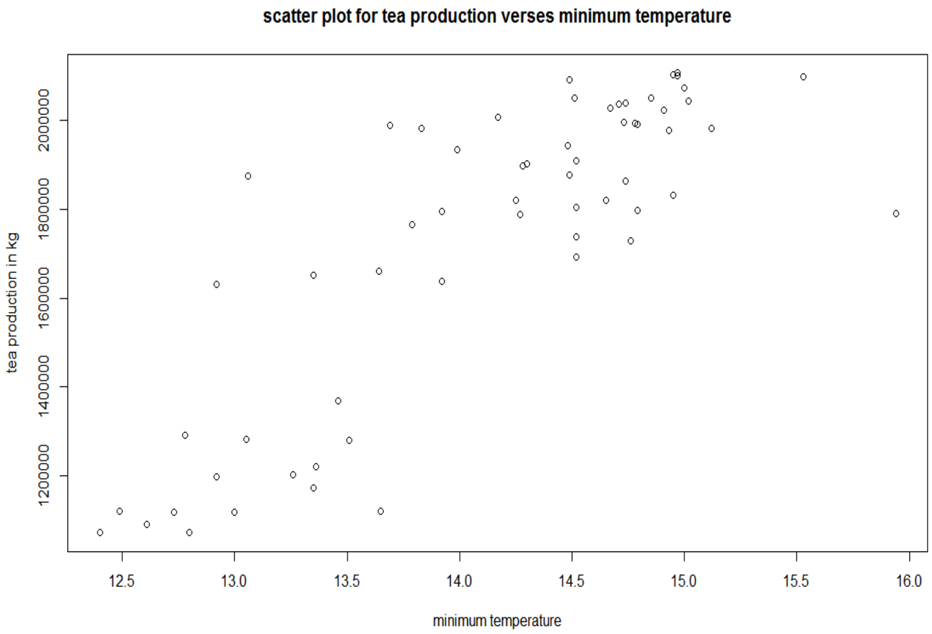

Figure 1: Scatter plot for Tea Production and Minimum Temperature.

Figure two below shows the scatter diagram for maximum temperature vs yield of tea. The possible impact of increased warming attributable to climate change can be deduced with maximum temperatures above the optimum ability to ruin tea plant production.

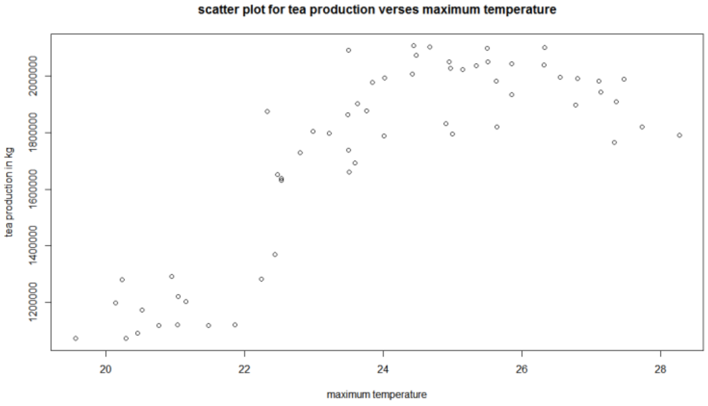

Figure 2: Scatter plot for Tea Yield versus Maximum Temperature.

Figure 3 below shows Scatter Diagram for Rainfall vs yield of tea in Murang'a County with Minimum Linearity.

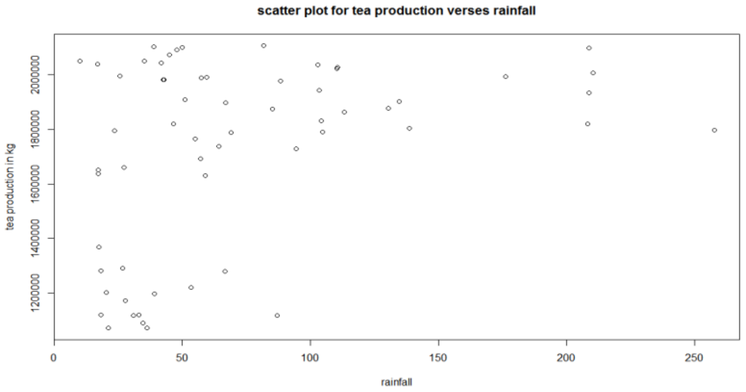

Figure 3: Scatter Plot for Rainfall versus Tea Production.

3.3.Regression model Specification

The initial model estimates (Appendix II) gave non-significant p-value greater than 0.05 at 95% confidence level. This prompted the re-specification of the model excluding rainfall variable (Appendix III). The p-value for minimum and maximum temperature estimates were found to be statistically significant at 95% confidence level. Consequently, the model was specified as

$$\text{Yield} = -\,2836611 + 209888\,\text{Temp}_{min} + 66798\,\text{Temp}_{max} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (v)$$

Where Temp_{min} and Temp_{max} are minimum and maximum temperatures respectively.

3.3.1. Residual plots

Residual plot carried out to identify and remove possible outliers are shown in Figure 4 below. They revealed the presence of data outliers in the normal Q-Q plots; raising the need to re-specify the model without the outliers as seen in 3.3.2 below.

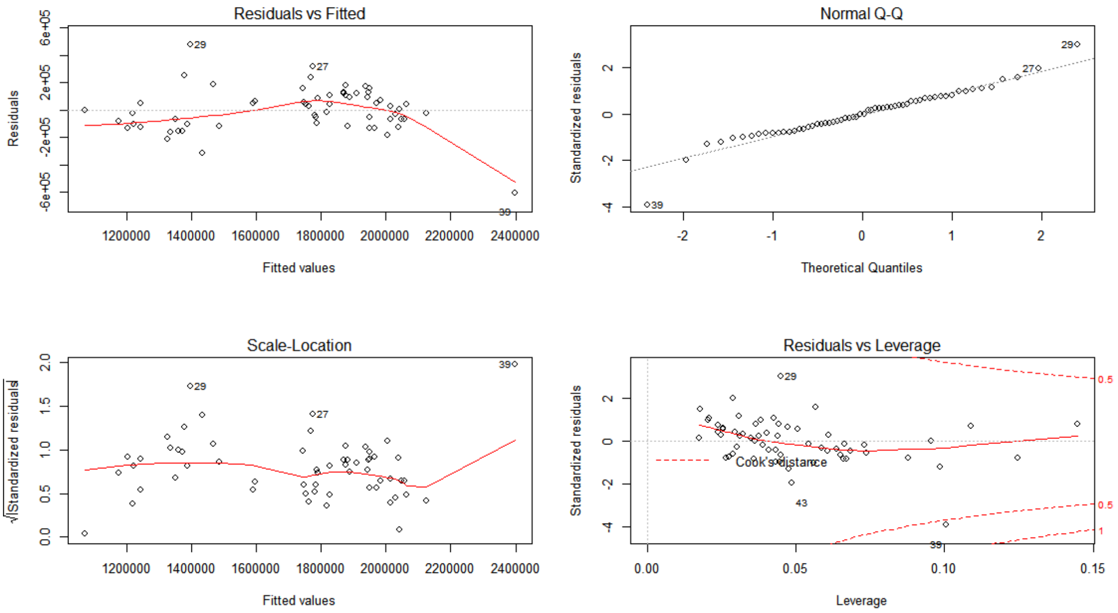

Figure 4: Model Residual Plot.

3.3.2. Results of Model re-specification

The need to specify a model without outliers was addressed as seen in appendix IV. The outcome was tested by re-plotting the residuals as seen in figure 5 below. A multicollinearity test was carried out with tea as the dependent variable and results revealed a non-perfect collinearity as shown in appendix V.

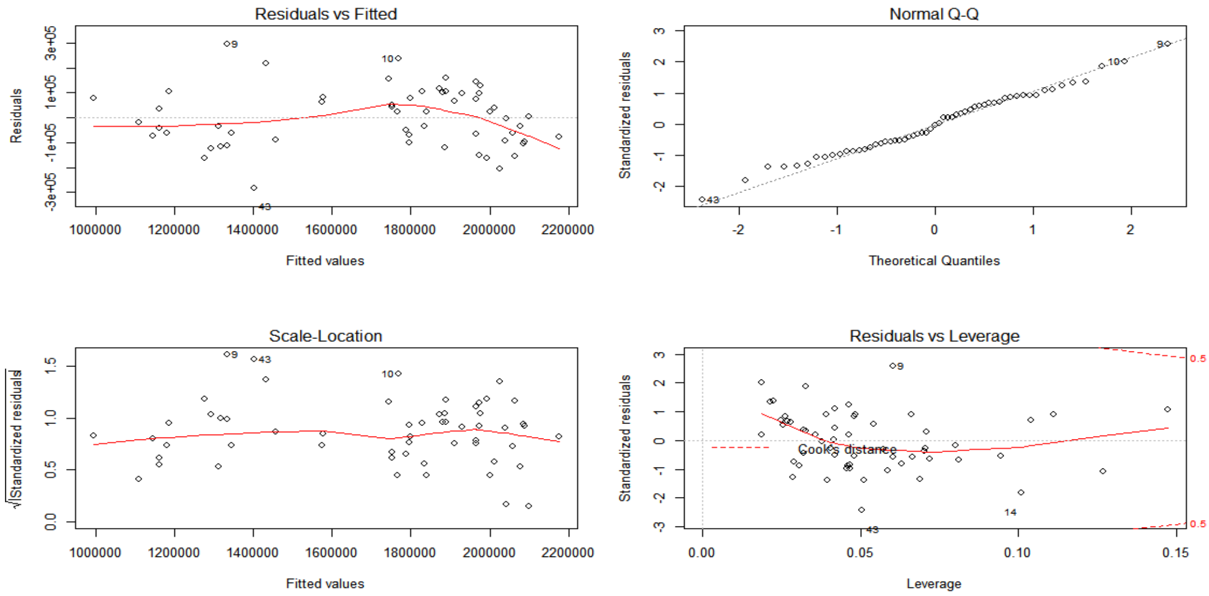

Figure 5: Model Residual Plot without Outliers.

4. SUMMARY, CONCLUSION AND RECOMMENDATION

4.1. Study summary and Conclusion

This study investigated the relationship between three climate variables namely maximum and minimum temperatures, rainfall with tea yield over Murang'a County in Kenya. Correlation analysis was carried out to determine the associative relationships between the climate variables and yield. Strong positive correlation values were observed in both minimum and maximum temperature with yield while a weak positive correlation was observed between rainfall and tea yield respectively.

Multiple regression model was designed in three steps with initial utilization of all climate variables and through setting level of significance as 5%. Rainfall variable did not satisfy this condition and the second model was redesigned excluding rainfall variable. The model was tested using residual plotting.

The results of this investigation show that an increase in maximum temperatures increased the yield of tea up to optimum temperatures beyond which tea production is curtailed by any further increase in temperatures.

The results also reveal that rainfall contributes to tea yield but with a weak associative relationship. This raises the possibility of other factors not within the scope of this investigation, contributory to tea yield including soil moisture, crop breeding and management practices among others. The study recommends future modelling research including such external factors.

4.2 Recommendation

Plant yield involves interaction with many factors. This study made attempt to statistically link climate changes to tea yield. Since there are others factors such as plant management, crop breeding, soil texture and other relevant externalities future research is encouraged that can generate a statistical relationship that incorporates all the experiments viable driver of tea crop yield.

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APPENDIX

Data sheet

Year	month	min.temp	max.temp	rainfall	teaprod
2014	jan	14.97	26.33	49.9	2101853
2014	feb	14.52	27.36	50.9	1909827
2014	mar	15.12	25.63	42.7	1982145
2014	apr	14.49	23.76	130.3	1878588
2014	may	14.52	22.99	138.5	1804226
2014	jun	13.36	21.04	53.4	1220621
2014	jul	12.73	20.76	87	1117833
2014	aug	13.51	20.23	66.7	1278773
2014	sep	12.92	22.53	58.9	1630239
2014	oct	14.17	24.42	210.3	2007673
2014	nov	14.52	23.59	57.1	1692793
2014	dec	14.95	24.67	38.8	2103049
2015	jan	13.69	27.47	57.4	1989169
2015	feb	14.25	27.73	46.4	1820546
2015	mar	14.48	27.14	103.3	1944352
2015	apr	14.91	25.15	110.4	2023659
2015	may	14.52	23.5	64.2	1738179
2015	jun	13.05	22.24	18.3	1281698
2015	jul	13.26	21.15	20.4	1201015
2015	aug	12.49	21.86	18.3	1120677
2015	sep	13.92	25	23.5	1794994

2015	oct	14.67	24.97	110.5	2028009
2015	nov	14.3	23.63	134.6	1901594
2015	dec	14.51	24.95	35.2	2050839
2016	jan	14.85	25.51	9.9	2050808
2016	feb	14.79	26.8	59.4	1991573
2016	mar	14.49	23.5	47.8	2093143
2016	apr	14.95	24.9	104.1	1830868
2016	may	13.06	22.33	85.1	1875502
2016	jun	12.92	20.14	39	1197524
2016	jul	12.8	20.29	21.1	1070786
2016	aug	12.78	20.95	26.7	1290770
2016	sep	13.92	22.53	17.2	1638096
2016	oct	13.99	25.85	208.6	1933453
2016	nov	14.27	24.01	68.9	1788224
2016	dec	14.71	25.34	102.9	2038312
2017	jan	13.83	27.11	42.6	1982922
2017	feb	14.28	26.77	66.9	1897995
2017	mar	15.94	28.27	104.7	1791598
2017	apr	15.53	25.5	208.8	2098904
2017	may	14.79	23.22	257.6	1797687
2017	jun	13.46	22.44	17.5	1368938
2017	jul	13.65	21.03	33	1119861
2017	aug	13	21.48	30.9	1116376
2017	sep	13.35	22.48	17.2	1651572
2017	oct	15.02	25.85	41.8	2043730
2017	nov	14.74	23.49	113.3	1864097
2017	dec	14.73	26.55	25.7	1995997
2018	jan	14.74	26.32	16.8	2039557
2018	feb	13.79	27.33	55.1	1765282
2018	mar	15	24.48	45	2072895
2018	apr	14.93	23.84	88.4	1977508
2018	may	14.76	22.8	94.3	1728836
2018	jun	13.35	20.52	27.8	1171424
2018	jul	12.4	19.56	36.1	1072802
2018	aug	12.61	20.46	34.5	1090917
2018	sep	13.64	23.51	27.3	1660651
2018	oct	14.65	25.64	208.2	1820587
2018	nov	14.78	24.02	176.1	1994618
2018	dec	14.97	24.44	81.6	2107179