Effect of Global Warming on Rainfall and Agriculture Production

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Agriculture production depends on rainfall. Global warming increases the temperature and affecting the rainfall of a country. PNG is an agricultural country. This paper analyse the average maximum and minimum temperatures and rainfall data for more than three decades obtained from thirteen Meteorological stations of PNG. This analysis revealed the long term variations in temperature and rainfall. It is observed that temperature is increasing significantly for most of the stations in PNG while in rainfall, decreasing trend exist though they are not statistically significant. Reduced rainfall is affecting the agriculture production of PNG.

Field of Research: Applied Economics

1. Introduction

Temperature and rainfall are key features of climate, which is defined as the prevailing weather conditions over an area. The atmospheric temperature is the degree of heat that is produced by the heating of the earth's surface, especially the ocean by the energy from the sun. Rainfall is the condensation of atmospheric moisture. Agriculture production depends on rainfall and atmospheric temperature. Rainfall is affected by the change of atmospheric temperature or global warming. In the recent years scientific research based on reliable world climate data reveal that the climate is being affected by the green house effect and temperature and precipitation are changing globally (IPPC, 2001).

This paper analyse the atmospheric temperature, rainfall and Agriculture production data of Papua New Guinea (PNG).

2. Literature Review

Global warming is the increase in the average temperature of the Earth's near-surface air and oceans. The global average air temperature near the Earth's surface rose 0.74 ±0.18 °C (1.33 ± 0.32 °F) during the hundred years ending in 2005. The Intergovernmental Panel on Climate Change (IPCC) concludes "most of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas

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concentrations" via the greenhouse effect. Natural phenomena such as solar variation combined with volcanoes probably had a small warming effect from pre-industrial times to 1950 and a small cooling effect from 1950 onward (Wikipedia, 2008). These basic conclusions have been endorsed by many scientific societies and academics of science including all national academies of science of the major industrialized countries while individual scientists have voiced disagreement with some findings of the IPCC, the overwhelming majority of scientists working on climate change agree with the IPCC's main conclusions.

Climate model projections summarized by the IPCC indicate that average global surface temperature will likely rise a further 1.1 to 6.4 °C (2.0 to 11.5 °F) during the twenty-first century. Increasing global temperature will cause sea level to rise and is expected to increase the intensity of extreme weather events and to change the amount and pattern of precipitation. Other effects of global warming include changes in agricultural production, trade routes, species extinctions and increases in the ranges of disease vectors.

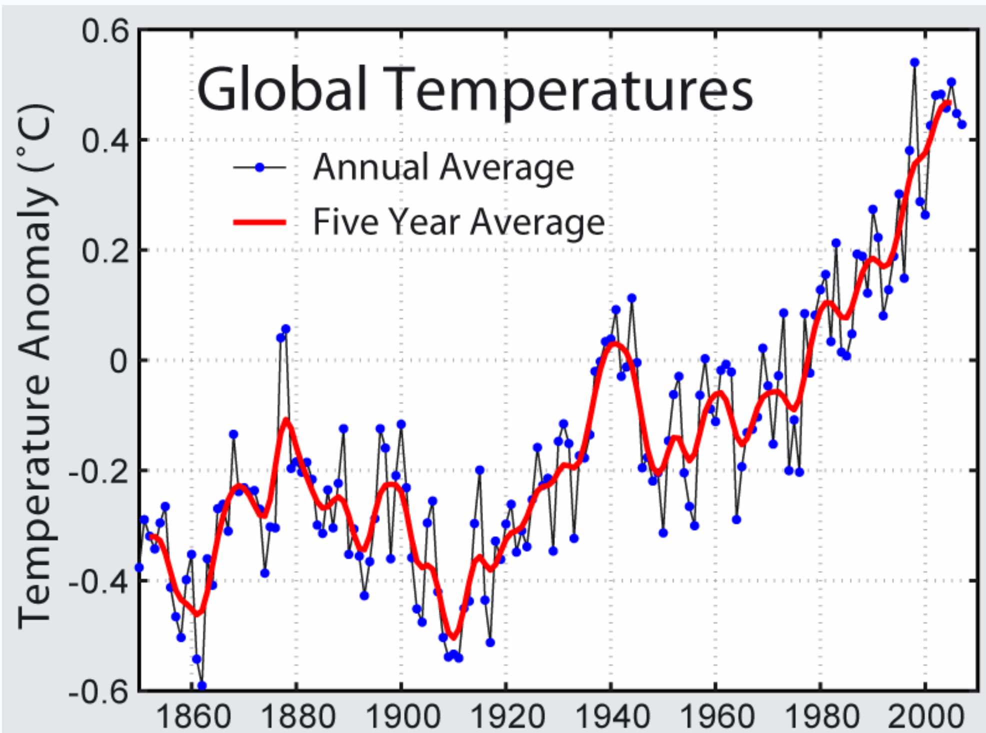

Figure 2.1 Global temperatures from 1850 to 2007

Remaining scientific uncertainties include the amount of warming expected in the future, and how warming and related changes will vary from region to region around the globe.

These findings motivate us to study the changes of temperature, rainfall and agriculture production of a developing nation named Papua New Guinea. The climate of PNG is tropical in nature due to its latitudinal position between the equator and 12^{o} south. Hence it generally has an annual pattern of wet (more rainfall) and dry (less rainfall) seasons. The wet and dry seasons are significantly influenced by the northwest (NW) and the southeast (SE) winds. The wet season occurs during the NW monsoon period that occurs between December and April. The highest rainfall is observed within this period. May is the shifting month in wind directions when the NW wind slowly subsides as the SE wind begins to blow. The SE wind lasts from May to October. This is a period of less rainfall. Some parts of PNG however, experience more rainfall during this season due to the effects of topography. These are areas with backing mountain ranges that lie in a perpendicular direction to the SE wind.

The temperature variation in PNG also shows annual variation. It is generally high from October to April and it drops in the mid year months. The temperature variation is influenced greatly by the cycle of the sun and the latitudinal position of an area. The seasonal variations in temperature occur as a result of the movement of the sun across the equator known as the equinox, which occurs twice a year. The spring equinox occurs on September 22 where the sun crosses the equator to the south, warming the southern hemisphere while temperature in the north decreases. The reverse occurs on March 21, which is known as the fall equinox. The highest and lowest temperatures are observed within the periods of the spring and the fall equinoxes respectively. The range of the variations varies with latitude. Areas in the higher latitudes experience more significant temperature variations. Other factors that may affect the temperature are topography, altitude and wind directions.

Temperature and rainfall are also influenced by the inter-tropical convergence zone (ITCZ) and the El Nino Southern Oscillation (ENSO) events. The ITCZ is an area of low pressure that is formed when the winds in the northern and the southern hemispheres meet near the equator. These winds converge at their meeting point causing an upward flow of moist air, which condenses in the air and releases heavy rain. The movement of the sun directly influences the movement of the ITCZ. The ITCZ moves in the direction of intense solar heated surfaces (Rosenberg, 2006). Therefore, more rainfall occurs in PNG when the southern hemisphere is warmer.

ENSO events have tremendous effects on the temperature and rainfall of PNG. Extreme rainfall seasons occur during La Nina (flood) events while extreme low rainfall during El Nino (drought) events. Historical records showed that the global cycle of ENSO occurs every two to seven years with an average cycle of four years (Jacques and Voituriez, 2000). The El Nino years (in relation to the length of available data of PNG temperature and rainfall data) are 1972/1973, 1982/1983, 1986/1987/1988, 1991/1992, 1994/1995, 1997/1998. The La Nina years are 1970/1971, 1973/1974, 1975/1976, 1988/1989, 1998/1999. The most extreme ENSO events occurred in 1982 and 1997, a period of 15 years (Jacques and Voituriez, 2000). The El Nino and La Nina years correspond with the El Nino and La Nina events in PNG.

The analysis of this paper was aimed at identifying the long-term movement or trend of temperature, rainfall and agriculture production of PNG.

3. Data

The data used in this project are the yearly averages for rainfall and for minimum and maximum atmospheric temperatures. The yearly averages were calculated from the daily readings that are recorded every 24 hours. These data have been provided by the Papua New Guinea National Weather Service located in Port Moresby. Yearly agriculture production of main agriculture products such as Tea, Copra, Copra oil, Rubber, Cocoa, Coffee and Palm oil are also considered.

The temperatures are measured using the dry and the wet bulb mercury thermometers, which are set to read maximum and minimum temperatures respectively. The readings on the thermometer remain unchanged at the maximum or the minimum peak until it is reset for another 24 hours reading. The rainfall readings are measured using a standard rainfall gauge. The recordings of the rainfall are also made 24 hourly.

The rainfall and temperature data are for thirteen meteorological stations located at the airports around the country (Table 3.1). All these stations are situated in coastal provinces. Kiunga is located further inland in the Western Province and it is close to the highlands.

Station	Years of available data	Total
Momote	1968 - 2003	36
Port Moresby	1970 - 2003	34
Madang	1973 - 2003	31
Daru	1973 - 2003	31
Kavieng	1973 - 2003	31
Wewak	1973 - 2003	31
Misima	1975 - 2003	29
Rabaul	1974 - 1994	21
Nadzab	1979 - 2003	19
Gurney	1990 - 2003	14
Kiunga	1994 - 2003	10
Tokua	1994 - 2003	10
Hoskins	1996 - 2003	8

Table 3.1 Years of available data for the thirteen stations in PNG.

Table 3.1 shows the thirteen meteorological stations, the years of available data for maximum and minimum temperatures and rainfall, and total number of years of available data. The stations are arranged in descending order of the total number of years of available data. The total number of years of available data varies for these stations since these stations were set up in different years. The last three stations however, may not be suitable for long-term analysis since the length of available data is short. These three stations were also set up in a decade of ‘problem years’ due to weather instability (Maiha, 2006).

Table 3.1 also shows that all the stations have data up to the year 2003 except Rabaul, which has its data up to 1994. This was due to a volcanic eruption in 1994, which resulted in the closure of the Rabaul meteorological station. The station was moved to the new airport, Tokua. Nadzab station also had six years of missing data from 1981 to 1986. The weather station was moved to Lae in 1981 and back to Nadzab in 1987. The thirteen meteorological stations of PNG are shown on the map below.

PAPUA NEW GUINEA

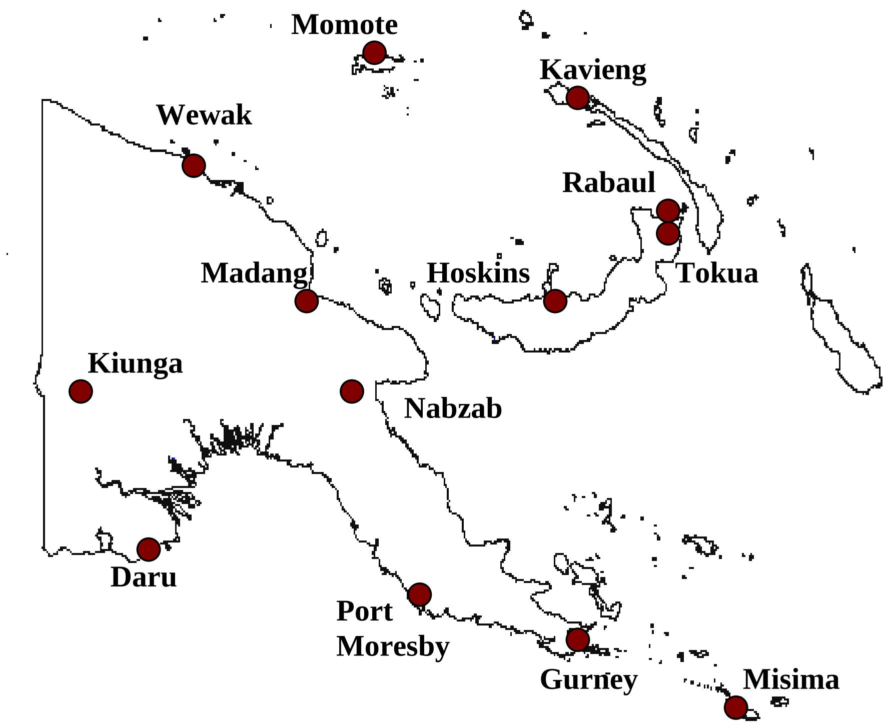

Figure 3.1 Thirteen meteorological stations in PNG

4. Methodology and Research Design

Temperature, rainfall and agriculture production data are made over time and therefore are referred to as time series data, which is defined as a sequence of observations that varies over time. The time series is made up of four components known as seasonal, trend, cyclical and irregular (Patterson, 1987). Trend is defined as the general movement of a series over an extended period of time or it is the long-term change in the dependent variable over a long period of time (Webber and Hawkins, 1980).

Since the trend variation occurs over a substantial extended period of time, the stations with ten and below years of available data were considered unsuitable for the trend analysis. Therefore Tokua, Hoskins and Kiunga stations were excluded from this analysis.

Trend is determined by the relationship between the two variables (temperature and time or rainfall and time or agriculture production and time).

4.1 Linear regression

The linear regression line was fitted using the most common method of least-squares. This method calculates the best fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line. If a point lies exactly on the straight line then the algebraic sum of the residuals is zero. Residuals are defined as the difference between an observation at a point in time and the value read from the trend line at that point in time. A point that lies far from the line has a large residual value and is known as an outlier or, an extreme value.

The equation of a linear regression line is given as (Hays, 1981),

$y = a + bx$

where, y is the observation on the dependent variable

x is the observation on the independent variable

a is the intercept of the line on the vertical axis and b is the slope of the line.

In order to fit regression lines scatter diagrams of the annual average temperature, rainfall and agriculture production (dependent variables) against time (independent variable) in years were plotted. Linear regression lines were then fitted to determine the trends of temperature, rainfall and agriculture production. The drawing of the scattered diagrams and the fitting of the regression lines were done in Microsoft Excel.

The scatter diagram and the trend line for one station named Madang are shown below to demonstrate the best fitted line that represents trend. The other stations have similar diagrams.

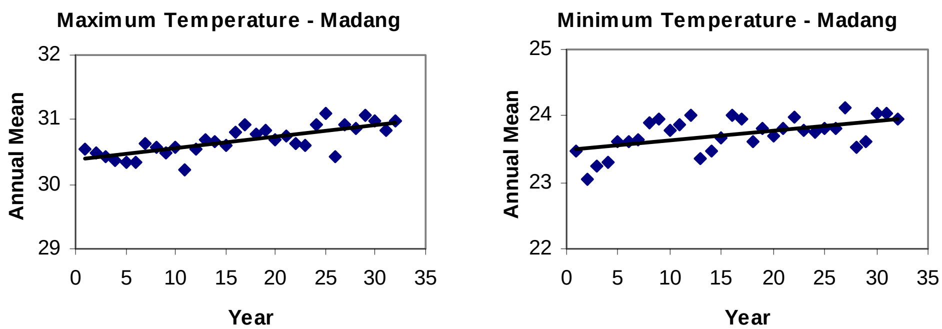

Figure 4.1 Scatter diagrams with trend line for Madang temperature.

Above diagrams indicate that temperature trend for Madang is increasing which implies there is a positive linear relationship between temperature and time.

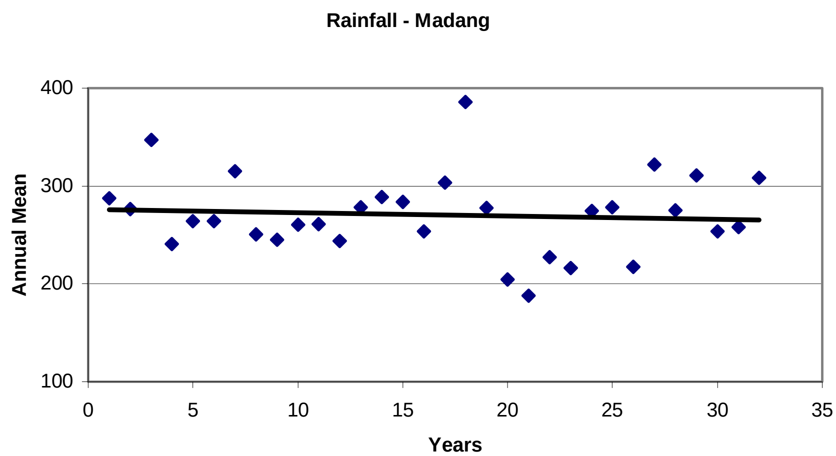

Figure 4.2 Scatter diagram with trend line for Madang rainfall.

Figure 4.2 shows that the trend of rainfall for Madang is slightly decreasing which indicates there is a negative linear relationship between rainfall and time.

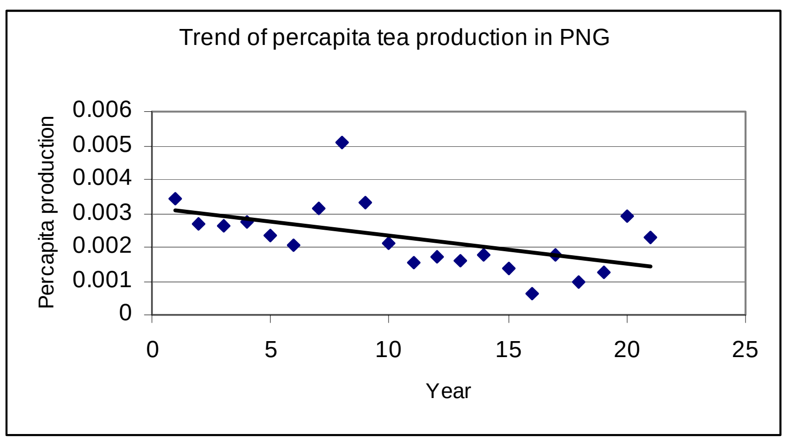

Figure 4.3 Scatter diagram with trend line for tea production in PNG

Figure 4.3 shows that the trend of per-capita tea production in PNG is decreasing which implies there is a negative linear relationship between tea production and time.

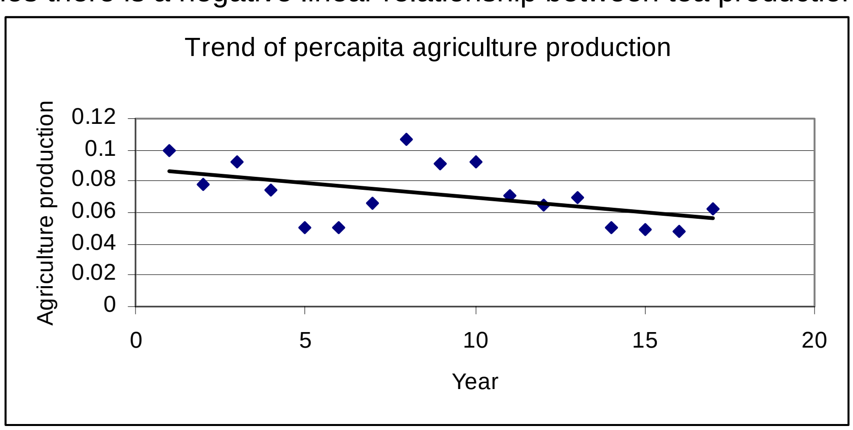

Figure 4.4 Scatter diagram with trend line for agriculture production in PNG

Figure 4.4 shows that the trend of per-capita agriculture production in PNG is decreasing which implies there is a negative linear relationship between agriculture production and time.

The strength of the linear relationship between the variable and time was then calculated to determine the trend of temperature, rainfall and agriculture production. These relationships are measured by the correlation coefficient.

4.2 Correlation coefficient

The correlation coefficient determines the strength of linear relationship between two variables. It always takes a value between –1 and +1, with 1 or –1 indicating a perfect correlation (all points would lie along a straight line in this case and having a residual of zero). A correlation coefficient close to or equal to zero indicates no relationship between the variables. A positive correlation coefficient indicates a positive (upward) relationship and a negative correlation coefficient indicates a negative (downward) relationship between the variables. The correlation coefficients between temperature, rainfall, agriculture production and time were calculated as follows.
Given the pairs of values $(x_1, y_1), (x_2, x_2)............(x_n, y_n)$, the formula (Webber and Hawkins, 1980) for computing the correlation coefficient is given by

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}$$

The correlation coefficients for 10 stations were calculated using the above formula. The results are shown in Table 4.1.

	Temperature		**Rainfall**
Station	**Max**	**Min**	
Wewak	0.52	0.88	-0.26
Madang	0.74	0.55	-0.13
Nadzab	0.43	0.35	-0.23
Momote	0.87	0.65	-0.07
Kavieng	0.86	0.82	-0.26
Rabaul	0.29	0.43	-0.07
Port Moresby	0.33	0.60	-0.11
Daru	0.27	0.13	0.01
Misima	0.51	0.52	-0.09
Gurney	0.23	0.21	0.06

Table 4.1 Correlation coefficients for temperature and rainfall.

Table 4.1 shows the correlation coefficient values that reflect the strength of the relationship between temperature and rainfall against time. All the stations showed positive relationships in temperature. Some stations show strong relationship while others weak.

In rainfall, most of the stations have negative relationships. However, all the correlation coefficient values are very small and that implies that the relationship between rainfall and time is weak. In agriculture production, the correlation coefficient between tea production and time is -0.516 and that for overall agriculture production is -0.499. This indicates that there exist negative relationship between agriculture production and time.In order to see the intensity of this trend, the significance of the correlation coefficient were tested.

4.3 Testing the significance of the correlation coefficient.

In testing the significance of the correlation coefficient, the following null (H_0) and alternative (H_1) hypothesis were considered.

Hypothesis:

$$\mathrm{H}_0 : \rho = 0$$

$$\mathrm{H}_1 : \rho \neq 0$$

where, ρ is the population correlation coefficient.

The appropriate test statistics for testing the above hypothesis is

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}}, \mathrm{d.f} = n-2$$

For example, calculating the test statistics for Kavieng maximum temperature gives

$$t = \frac{0.86\sqrt{(32-2)}}{\sqrt{(1-(0.86)^2)}}, \mathrm{d.f} = 32-2$$

$$= 9.230784$$

The following Table represents the values of the test statistic for various stations.

	Temperature		**Rainfall**
Station	**Max**	**Min**	
Wewak	3.35	10.36	-0.52
Madang	5.96	3.64	-0.70
Nadzab	1.72	1.35	-0.33
Momote	10.29	4.99	-0.31
Kavieng	9.23	7.73	-1.44
Rabaul	1.36	2.13	0.31
Port Moresby	1.99	4.31	-0.64
Daru	1.51	0.71	0.07
Misima	3.14	3.19	-0.46
Gurney	0.82	0.74	0.21

Table 4.2 Test statistics values for ten stations of PNG.

Also the test statistics values for tea production and overall agriculture production are -2.695 and -2.971 respectively.

4.4 Calculating P value

The P-values were then calculated in the following manner.

$$\text{P - value} = 2\text{P}\{\text{t} > \text{Observed value of the test statistic}\}$$

For example, calculating the P-value for Kavieng maximum temperature gives,

$$\begin{aligned}\text{P - value} &= 2\text{P}\{t > 9.230784\} \\ &= 2.85\text{x}\,10^{-10} \\ &\approx 0\end{aligned}$$

Since the P-value for Kavieng maximum temperature is so small, the null hypothesis is rejected. This implies that the correlation coefficient for temperature is statistically significant and a trend does exist for Kavieng maximum temperature.

The P-values for all the other stations were calculated as above and are shown in the following Table.

Station	Temperature		Rainfall
	Max	Min	
Wewak	0.00	0.00	0.61
Madang	0.00	0.00	0.42
Nadzab	0.11	0.20	0.75
Momote	0.00	0.00	0.18
Kavieng	0.00	0.00	0.16
Rabaul	0.19	0.05	0.76
Port Moresby	0.05	0.00	0.53
Daru	0.14	0.49	0.94
Misima	0.00	0.00	0.65
Gurney	0.82	0.47	0.84

Table 4.3 P-values for ten stations of PNG

Table 4.3 shows the P values for ten stations of PNG, which were used to determine the strength of linear relationship between the variables and time and thus establishing trend. The significance of the trend was tested at 5% level of significance. A trend exists if the P value is less than 0.05. P-values greater than 0.05 shows that trend is not significant.

The P-values for both maximum and minimum temperatures are very small for Wewak, Madang, Momote, Kavieng, Misima and Port Moresby. As the P-value is less than 0.05, the null hypothesis is rejected. This implies that the correlation coefficient for temperature is statistically significant for these stations.

Nadzab, Rabaul, Daru and Gurney have P-values greater than 0.05 and therefore the null hypothesis is not rejected. This implies that the correlation coefficients for temperature for these stations are statistically insignificant.

For rainfall, the P-values are large for all the stations and therefore the null hypothesis is not rejected. This implies that the correlation coefficient for rainfall is statistically insignificant though it is slightly decreasing.

The P-values for per-capita tea production and overall production are 0.014 and 0.008 respectively. This indicates that the correlation coefficient for per-capita tea production and overall agriculture production are statistically significant.

5. Conclusion

The trend analysis indicates that temperature is increasing significantly for most stations in PNG but insignificant increase is observed in Nadzab, Daru, Gurney and Rabaul. The rise in temperature is an indication of the effects of global warming in PNG. Rainfall is decreasing insignificantly in all the ten stations. Per-capita tea production and overall agriculture production are decreasing significantly.

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