Causes and Effects of Climate Variability in the Pacific Island of Papua New Guinea

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Abstract: The pacific island of Papua New Guinea is the third largest rainforest in the world. The forests help maintain the agricultural land and protect people and crops from floods and landslides. From year 2001 to 2023, there is a tree cover loss of 0.89% mainly due to deforestation and a small percentage of forest fire. This results in about five million tons of carbon dioxide emission per annum. An analysis has been done to study the spacial and temporal changes in the climate of Papua New Guinea using published meteorological parameters for a period 2001-2020. Dry and wet conditions in different regions of Papua New Guinea in different years were identified by calculating Rainfall Anomaly Index. It is observed that dry conditions prevail in some regions of the country due to warming of the atmosphere. Also, El Nina/La Nina events and deforestation influenced the climate to some extent.

Key words: Atmospheric temperature, rainfall, El Nino, La Nina, trend, rainfall anomaly index

1. INTRODUCTION

Global atmospheric temperature is increasing steadily and the projected rise in temperature will be 2^0 by 2100 (Yun Gao et al., 2017). Global surface temperature changed as doubling of atmospheric Carbon dioxide levels (Cubasch et al., 2001). Studies on extreme temperature events showed the importance climate change impacts (Hegerl et al., 2004; Tebald et al., 2006). Changes in photosynthesis and evapotranspiration are more affected by T_{max} and T_{min} (Dhakhwa and Camphbell, 1998). Like any other country, Papua New Guinea is vulnerable to climate change. It will affect agriculture, financial resources and many other factors. Farmers face a significant challenge. The change in rainfall has direct impact on farm productivity.

Climate variations in four regions; Port Moresby, Goroka, Nadzab and Kavieng, of Papua New Guinea, which have unique climate, were analyzed in this study. This study helps to increase our understanding of climate pattern and weather and provides insights into how these patterns change over time. Port Moresby is the capital city of Papua New Guinea which experiences tropical climate characterized by high temperature, high humidity and wet and dry seasons. Wet season is from November to April characterized by rain and thunder storms and dry season is sunny with less precipitation. Goroka is located in the Eastern Highlands Province which is known for its rugged terrains and landscapes. The elevation is about 1600 meters surrounded by steep mountains and deep valleys. The climate in Goroka is generally cool and temperate with average temperature ranging from 10-25^{0}C throughout the year. Coffee and tea plantations are the main crops grown in the area. Nadzab is a place in Lae which is located on the northern coast of PNG main land. The Bismarck Sea is in the north and the rain forest covered mountains are in the south. The climate is tropical with high temperature and humidity throughout the year. The region's weather is influenced by the South Pacific Convergence Zone (Kazuyo et al., 2014). Kavieng is situated on the western coast of an island New Ireland in Pacific Ocean which is a part of PNG. The climate of Kavieng is tropical with high humidity. The place is filled with green rainforests, beaches and coral reefs. The terrain is mountainous and the mountains are covered with rainforests and are home to a diverse range of flora and fauna. The wet season lasts from December to March with heavy rainfall and tropical cyclones. The dry season is from May to

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October with less rainfall and lower temperatures. The rainfall variability is very much related with El Nino and La Nina events (Ian et al., 2013).

It is important to study T_{max} and T_{min} separately when assessing climate change impact (David et al., 2007). The spatial and temporal changes in atmospheric temperature and rainfall are analyzed to study climate change in Papua New Guinea. By studying the localized variation, we can develop strategies to mitigate its impact. In this study, we analyzed the daily maximum temperature (T_{max}) and daily minimum temperature (T_{min}) and rainfall from 2001 to 2020 in four regions of Papua New Guinea. We also analyzed the forest loss and green loss in these regions in the same period. The variation of rainfall during El Nino-La Nina events were also studied. This study is useful in developing strategies for mitigation and build resilience against extreme climate events.

1.1 Data Analysis

The data used in the study are the monthly average values of maximum and minimum values of the atmospheric temperatures and the monthly rainfall data measured in various centers namely POM, Goroka, Nadzab and Kavieng for the period from 2001 to 2020 published by Meteorological Department, Papua New Guinea. The forest loss data is taken from PNG Conservation and Environment Protection Agency (https://www.globalforestwatch.org). The SST and SOI data are taken from NASA website. (https://www.ncei.noaa.gov).

1.2 Trend Analysis

Significant trend of a time series can be found out by either parametric or non-parametric methods. If the data is independent and normally distributed, parametric method is used whereas if the data is only independent, non-parametric method is used (Gocic and Trejkovic, 2013). In this analysis, we used Mann-Kendall and Sen's slope estimator which are non-parametric in nature. Mann-Kendall test is used to determine the sense of the trend whether it is increasing or decreasing whereas Sen's slope estimator is used to determine the magnitude of the trend.

The Mann- Kendall statistics is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (1)$$

where x_i and x_j are the data values in the time series I and j respectively and n is the total number of data points.

$$sgn(x_j - x_i) = \begin{cases} +1 \; if \; x_j > x_i \\ 0 \; if \; x_j = x_i \\ -1 \; if \; x_j < x_i \end{cases} \quad (2)$$

If the number of observations is more than 10, Mann-Kendall statistic follows normal distribution with variance σ^2 given by

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

Z test is used to test the significance of the trend. The standard Z statistic is given by

$$Z_s = \begin{cases} \frac{S-1}{\sigma} \; if \; S > 0 \\ 0 \quad if \; S = 0 \\ \frac{S+1}{\sigma} \; if \; S < 0 \end{cases} \quad (4)$$

If $Z_s > Z_{table}$, the null hypothesis is rejected or a significant trend exists.

To determine the magnitude of the trend, Sen's slope estimator is used. The amount of change in parameter per unit time Q is given by

$$Q = \frac{x_j - x_k}{j-k}, k \neq j \tag{5}$$

For the time series data X of n values, N = n(n-1)/2 values of Q can be calculated. The Sen's slope estimator Q^* is the median of the N values of Q.

$$Q^* = \begin{cases} Q_{(N+1)/2} & if\ N\ is\ odd \\ \frac{Q_{(N/2)} + Q_{(N+2)/2}}{2} & if\ N\ is\ even \end{cases} \tag{6}$$

The numerical value of Q^* gives the degree of steepness of the trend.

1.3 Rainfall Anomaly Index

RAI is used to determine the anomaly in rainfall in a year whether it is positive or negative (Van-Rooy, 1965). To calculate RAI, the yearly rainfall data is arranged in the descending order and the average of the ten highest values is taken as the positive threshold value and the average of the ten lowest values is taken as the negative threshold value. The positive and negative threshold values are assigned +3 and -3 respectively. The positive and negative anomaly values are classified into six classes ranging from extremely wet to extremely dry conditions. Positive values are classified by wet conditions and negative values are classified by dry conditions.

$$RAI = 3\left(\frac{RNF - RNF_m}{X - RNF_m}\right) \quad for\ Positive\ anomaly \tag{7}$$

$$RAI = -3\left(\frac{RNF - RNF_m}{Y - RNF_m}\right) \quad for\ Negative\ anomaly \tag{8}$$

where RNF = current yearly rainfall (mm), RNF_m = average of the yearly rainfall for the period of study, X = the positive threshold value of rainfall and Y = the negative threshold value of the rainfall.

2. RESULTS AND DISCUSSION

The trend of variation of atmospheric temperature is determined by Mann-Kendall statistics and Sen's slope indicator. The yearly average values of T_{max} and T_{min} are calculated and the Z values of Mann-Kendall and Sen's slope indicators are calculated using the relations (1)-(6). Table 1 gives the Z values of Mann-Kendall and Sen's slope indicators of T_{max} and T_{min} in PNG and also in the four regions POM, Goroka, Kavieng and Nadzab. In PNG, a significant positive trend is observed in both maximum and minimum temperatures of the atmosphere. An increase in trend of 0.02^0 C per year is observed in maximum temperature whereas an increase in temperature of 0.015^0 C per year is observed in minimum temperature. If we observe the trend of variation in POM, Goroka, Kavieng and Nadzab, a significant increasing trend of T_{max} is observed in POM with an increase of 0.013^0 C per year. A significant increase in trend of T_{min} is observed in Goroka and Kavieng with an increase of 0.016^0 C and 0.023^0 C per year respectively. In other regions the trend of variation is not significant.

Table 1: The yearly mean maximum and minimum temperatures and the trend of variation of Tmax and Tmin in POM, Goroka, Kavieng, Nadzab and in Papua New Guinea.

	T max			**T min**		
	Mean T	**Zs**	**Sen's Slope**	**Mean T**	**Zs**	**Sen's Slope**
POM	31.47	**1.75**	**0.0126**	23.44	0.65	0.0061
Goroka	26.52	1.52	0.0112	15.8	**1.85**	**0.0159**
Kavieng	31.36	0.62	0.0258	24.23	**3.63**	**0.0225**
Nadzab	29.43	0.49	0.2912	22.92	-1.49	0.0064
PNG	30.43	**2.69**	**0.022**	23.69	**2.72**	**0.015**

2.1 Deforestation in Papua New Guinea

Tropical forests are important in mitigating climate change. Tropical forests play a crucial role in climate control by regulating temperature, rainfall, wind and cloud cover by storing large volumes of Carbon (IPCC, 2007). Release of large volumes of carbon in the atmosphere through human activity disturb the balance of the biosphere. Deforestation and forest fires release a large amount of carbon to the atmosphere (CIDA, 2001; Stern, 2007; Nepsted et al., 1999). About 80% of Papua New Guinea's land area is classified as forest. A decrease of 2.7% of forest area or 4.2% of tree cover loss is observed during 2002-2022 period. Forest loss in different regions is shown in Fig. 1. Forest loss was observed to be more in island region (red bars in Fig.1) and less in highland region (green bars in Fig.1). Forest loss in NCD (including POM) is 3.5, in Morobe (including Nadzab) is 2.4, in Eastern Highland (including Goroka) is 1.5 and in East New Britain (including Kavieng) is 9.

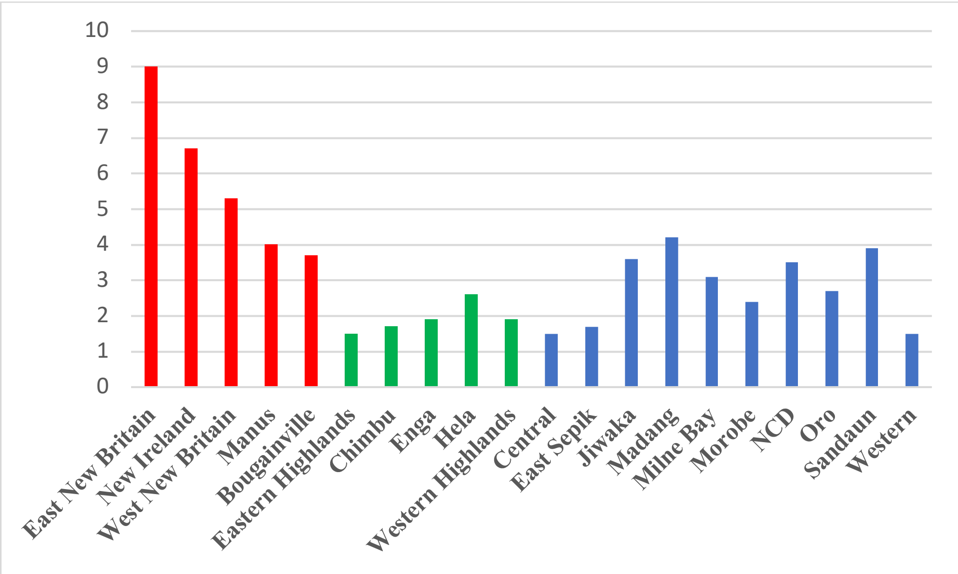

Fig. 1: The percentage of forest loss in different regions of Papua New Guinea

2.3 Rainfall Variability

The rainfall data for the period from 2001 -2020 is separated into wet season (from October to March) and dry season (from April to September) and the trend of variation is determined (Table 2). A significant positive trend of 3.27 mm/year is obtained in PNG and an increase in trend of 15.71mm/y in Nadzab during the dry season. In Goroka, an increase in trend of 8.63 mm/y is obtained during the wet season.

Table 2: The yearly mean rainfall and the trend of rainfall variability in POM, Goroka, Nadzab and Kavieng.

	Wet season			**Dry season**		
	Mean Annual Rainfall	**Zs**	**Sen's Slope**	**Mean Annual Rainfall**	**Zs**	**Sen's Slope**
POM	975	0	0.53	252	1.62	4.1
Goroka	1262	**3.37**	8.63	583	0	0.03
Kavieng	1736	-0.19	0.9	1499	-0.45	3.81
Nadzab	874	1.49	6.49	779	**2.43**	15.71
PNG	1212	1.13	4.59	778	**2.59**	3.27

2.4 Rainfall Anomaly Index

The yearly average values of rainfall are calculated for the period 2001-2020. The RAI for each year is calculated using equations (7) and (8). The years for which RAI values lie between -1 and +1 are considered 'Normal'. The year in which RAI value is in the range -3<RAI<-2 is taken as 'Dry' and RAI<-3 is considered as 'Extreme Dry'. Similarly, 2<RAI<3 and RAI>3 is considered 'Wet' and 'Extreme Wet' respectively. The calculated rainfall anomaly indices in the four regions are plotted in Fig. 2. Table 3 represents the years which fall in extreme dry, dry, normal, wet and extreme wet conditions. The percentage of periods where dry, wet and conditions prevail are calculated and tabulated in Table 4.

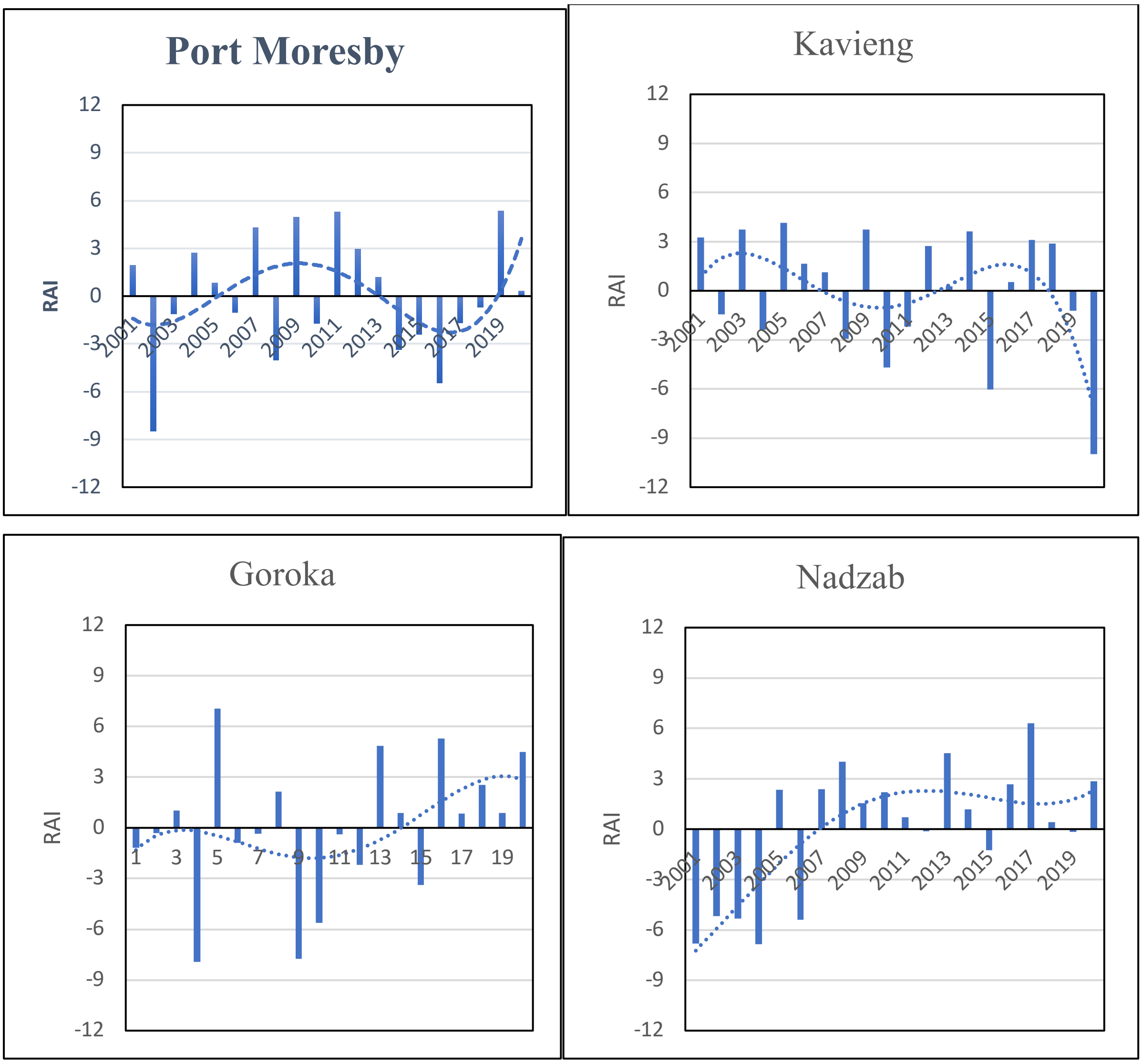

Fig. 2: Variation of RAI from 2001 to 2020 in POM, b) Goroka, c) Kavieng and d) Nadzab.

Table 3: Classification of years which are Dry, Extreme Dry, Wet and Extreme Wet for POM, Goroka, Kavieng and Nadzab for the period 2001-2020.

Region	Years				
	Extr. Dry	**Dry**	**Normal**	**Wet**	**Extr. Wet**
POM	2002, 2008, 2016	2014, 2015	2001, 2003, 2005, 2006, 2010, 2013, 2017, 2018, 2020	2004, 2012	2007, 2009, 2011, 2019

Goroka	2004, 2009, 2010	2012, 2015	2001, 2002, 2003, 2006, 2007, 2011, 2014, 2017, 2019	2008, 2018	2005, 2013, 2016, 2020
Nadzab	2001, 2002, 2003, 2004, 2006		2009, 2011, 2012, 2014, 2015, 2018, 2019	2005, 2007, 2010, 2016, 2020	2008, 2013, 2017
Kavieng	2010, 2015, 2020	2004, 2008, 2011	2002, 2006, 2007, 2013, 2016, 2019	2001, 2003, 2009, 2012, 2014, 2017, 2018	2005
PNG				2010	

Table 4: Percentage of years where Dry, Wet and Normal conditions prevail for the period 2001-2020.

	% of years where Dry, Wet and Normal conditions prevail		
	Dry	Wet	Normal
POM	25	30	45
Goroka	25	30	45
Nadzab	25	40	35
Kavieng	30	40	30
PNG	0	5	95

From Table 4, we can see that the rainfall condition is normal for 95% of time.

2.5 Climate variability due to El Nino-La Nina events

The Sea Surface Temperature (SST) anomaly in the Nino 2-3 region for the period 2001-2020 is used to find out the El Nino-La Nina events. Fig. 3 represents the variation of SST during the period of study. Anomaly greater than +5 is taken as El Nino event and less than -5 is taken as La Nina event. Table 5 gives the El Nino-La Nina years for the period of study.

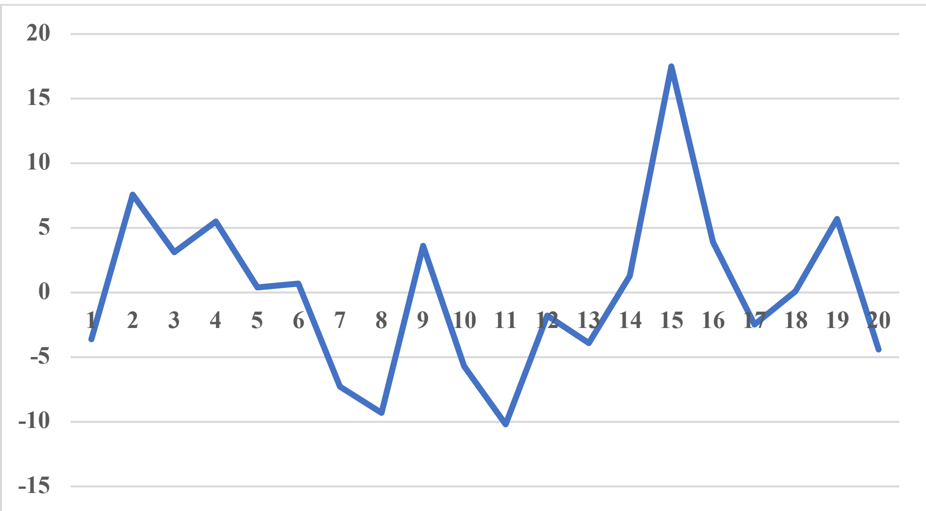

Fig. 3: Variation of Sea Surface Temperature Anomaly from 2001 to 2020.

Table 5: El Nino and La Nina years during 2001-2020.

El Nino				La Nina			
Weak	**Moderate**	**Strong**	**Very Strong**	**Weak**	**Moderate**	**Strong**	**Very Strong**
2004-05	2002-03		2015-16	2005-06	2011-12	2007-08	
2006-07	2009-10			2008-09	2020-21	2010-11	
2014-15				2016-17			
2018-19				2017-18			

2015 is a year of strong El Nino period where POM, Goroka and Kavieng experienced dry conditions. Forest loss is more in the Island region (Fig. 1) which includes Kavieng, which experienced extremely dry conditions (Table 3). During 2007-08 and 2010-11 years, La Nina conditions were strong (Table 5). In these periods, POM, Goroka and Nadzab experienced wet or extreme wet conditions (Table 3). But Kavieng experienced dry condition in these periods. PNG rainfall was found to be normal for 95% of years during the entire period of study (Table 5). This shows that even though the atmospheric temperature in different regions show an increase in trend, PNG's rainfall was not affected by global warming. Changes in rainfall are altered by El Nino-La Nina effects.

3. CONCLUSION

Climate change occurs due to global warming and other events such as El-Nino and La Nina events. Due to climate change, extreme conditions like extreme dry and extreme wet conditions occur which in turn affects agriculture and has connection with socio-economic systems of the country. The present study reveals that there is an increase in trend of atmospheric temperature with an increase of 0.02^0 C per year in Papua New Guinea. The rainfall is more or less the same everywhere except Goroka in wet season and Nadzab in dry season. Rainfall in POM, Goroka and Kavieng were found to be less during strong El-Nino events. Also, extreme wet conditions were observed in strong La Nina events.

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