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Climate change and rainfall in the Pacaya Samiria National Reserve

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A B S T R A C T

Rainfall and temperature are essential inputs for agricultural production, especially climate change-related ones. In turn, it is necessary for the development and survival of both men and animals at all biotic levels. In a reserve of great importance for the country, such as the Pacaya Samiria, these two factors play a preponderant role in the survival of animals and inhabitants of it. In this paper, VAR analysis with Granger's causality was used to determine the relationship between both variables. It was shown that there was a short-term positive relationship between climate change and rainfall in Pacaya Samiria.

1. Introduction

Temperature is an essential but unstable variable in the context of global climate change (Liu et al., 2023). Heated by radiation from the sun, fresh and salty waters evaporate, which move through winds in the atmosphere, then condense to form clouds and return to Earth through rain or snow, known as the water cycle (The Royal Society, 2021). Moreover, extreme hydrological changes manifest in events typically defined as floods or droughts (Wehner et al., 2017).

Flood is associated with heavy rainfall, while droughts are related to a lack of rain and often high temperatures that contribute to drying out the land (Liu et al., 2023). On the one hand, floods are commonly confined to defined areas and tend to last a short time, while droughts are extensive and last for months or even years (Camilloni et al., 2020). With human intervention, droughts and floods can be managed through irrigation or drainage (Mazzoleni et al., 2021). However, in a context of a natural park-like Pacaya Samiria, this is virtually impossible.

In addition, floods and droughts have a millionaire impact on human activities in the surroundings without counting human and animal lives.

Therefore, the Committee on Climate Change and U.S. Transportation Transportation Research Board Division on Earth and Life Studies (2008) presented an overview of the current understanding of the impacts of climate change in the United States, including that warming will tend to be greater, especially at high latitudes. The study suggests that future weather conditions would have less snowfall and rain, less snow development, and less melt runoff. The report also suggests that warming will lead to heavier rains that tend to be interspersed with relatively dry more extended periods.

Shifting the focus to extreme precipitation events, The Royal Society (2021) published that climate change will likely make precipitation less frequent but more intense in many areas and suggests that precipitation extremes are likely to increase, an already observed effect.

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Precipitation varies yearly and over decades with changes in amount, intensity, frequency, and type (Rashid & Wahl, 2022). On the one hand, moderate rainfall benefits plants, while identical amounts of rainfall in a short period can cause flooding and local runoff, leaving soils drier at the end of the day (Ekolu et al., 2022). At the same time, there is growing evidence that human-induced climate change, also called "global warming," is changing precipitation and hydrological cycles to extremes never seen before (Intergovernmental Panel on Climate Change, 2021). That is why this article will focus on knowing the impact of climate on the level of rainfall in the Pacaya Samiria National Reserve.

The Pacaya Samiria National Reserve is one of Peru's largest Protected Natural Areas, with an area of 2,080,000 hectares. This reserve was established in 1940 to protect the Paiche, the largest freshwater fish in the world. This reserve currently extends through the basin of the Pacaya and Samiria rivers (Servicio Nacional de Áreas Naturales Protegidas, 2012). This reserve has an internationally recognized biological and ecological importance (Yahuarcani et al., 2008).

The Pacaya Samiria National Reserve Administration protects the most significant expansion of floodplain forest in the Peruvian Amazon by offering a variety of resources to the scarce human population in the area (Dourojeanni, 2014). Consequently, the reserve's inhabitants mostly have a subsistence lifestyle (Dourojeanni, 2014).

Significant advances are in managing natural resources in Pacaya Samiria (Fundación Peruana para la Conservación de la Naturaleza, 2015). For example, management plans have been approved for fisheries and forest resources (Fundación Peruana para la Conservación de la Naturaleza, 2015). However, illegal logging, fishing, and hunting persist, and climate change's devastating effects can affect the park's fragile ecological balance (Campanera, 2017). As mentioned above, some populations live on the reserve, then the impact of climate change exceeds the wild environment.

The rainfall level, measured monthly and annually, is essential for preserving the reserve. As stated above, extreme floods and droughts undermine any survival effort for the area's inhabitants. Hence, it is necessary to know how climate change could affect the reserve's rainfall level. Consequently, the current research aimed to analyze the relationship between climate change, expressed by the temperature, and the monthly rainfall level of the Pacaya Samiria park from 2013 to 2021.

2. Literature Review

Hoerling et al. (2010) showed that it remains challenging to attribute historical precipitation variability to anthropogenic forcings or climate change. We evaluated regional precipitation data from around the world for 1977-2006. He argues that the relationship between sea temperatures and rainfall changes is generally not the product of human-induced emissions such as greenhouse gases and aerosols. Instead, their results suggest that trends during this period are consistent with the atmospheric response to observed sea surface temperature variability. Moreover, Tarmizi et al. (2019) studied the impact of climate change on rainfall. Therefore, a General Circulation model was employed to simulate the effect estimate. It was found that climate change negatively impacted rainfall since it occasionnally dries in Indonesia. Furthermore, Al-Ansari et al. (2014) studied the long-term relationship between climate change and rainfall in the northwest region of Iraq. Hence, they employed official government data and regressions to estimate associations. Consequently, they found that climate change negatively affected rainfall since the last one has been decreasing in millimeters. Ilbay-Yupa et al. (2021) analyzed the climate change on precipitation in the Guayas River Basin in Ecuador. Then, it was found that temperature increases will directly affect precipitations. It was observed mainly in the highland and the rainforest coast. Trenberth (2011) found that the rainforest level has decreased in tropical areas while the flood has grown. Then, adverse climate changes like El Niño became more frequent. Ncoyini and Savage (2022) found that in the Midlands region of South Africa, the farmers were susceptible to variations in the temperature. Then, the study developed a forecasting model to predict the relationship between air temperature and rainfall. Consequently, it was found that there would be a posstive relationship between temperature and precipitation level in the short term. Nonetheless, it seems to be reversed from 2050 and years later.

3. Theoretical Basis

It is necessary to emphasize that precipitation is the general term for rain, snowfall, and other frozen or liquid water that fall from clouds (Rashid & Wahl, 2022). These are intermittent but largely depend on temperature and weather (Liu et al., 2023). The latter determines storms and moisture supply through winds and evaporation from the surface, which in turn form clouds (Intergovernmental Panel on Climate Change, 2021). As the air warms above freezing, precipitation turns to rain. The exact process is essential for precipitation (Rashid & Wahl, 2022). As air rises to regions of lower pressure, it expands and cools, and cooling causes water vapor to condense and get form (Liu et al., 2023). Consequently, changes in temperature provide a very fundamental restriction on the amount of precipitation and type through the air's water vapor content (Mazzoleni et al., 2021). The conceptual basis for changes in precipitation has been given by Held & Soden (2006). Then, precipitation problems relate to changes in the location, type, quantity, frequency, intensity, and duration of precipitation (Held & Soden, 2006). Hence, the changes due to climate change tend to be extreme. Heating accelerates the drying of the Earth's surface as the heat increases and the consequent evaporation of moisture (Rashid & Wahl, 2022). It can increase the incidence and severity of droughts, which have been observed in many parts of the world (Aiguo et al., 2004). Atmospheric winds then carry this atmospheric moisture to where storms are favored. Therefore, increased water vapor leads to more intense precipitation but can also reduce rainfall events' duration and frequency (Camilloni et al., 2020). According to Rashid and Wahl (2022), warmer climates lead to more intense precipitation due to growing water vapor quantity, even when the total annual rainfall level is slightly reduced. Therefore, when the temperature increases, it increases the risks of drought and floods when it rains. For example, the summer of 2002 in Europe brought widespread flooding but was followed by record heat waves and droughts a year later in 2003 (Alpert et al., 2002). The distribution and timing of floods and droughts are most profoundly affected by the El Niño phenomenon, especially in the tropics (The Royal Society, 2021). Therefore, even though the potential for heavier precipitation is produced by increased water vapor, the amounts, duration, and frequency of events may be reduced as it takes longer to recharge the atmosphere with water vapor. Although the debate about whether a human or natural source causes Earth's temperature rise, it is no secret that the Earth is warming (Hoerling et al., 2010). Hence, it can cause droughts in certain places and flooding in others (Wehner et al., 2017). Therefore, it is necessary to know the effect of climate change on the rainfall level of Pacaya Samiria Reserve

4. Methodology

First, it is necessary to analyze whether the series is stationary or has unit roots. Determining whether cointegration exists between the variables is essential, which could lead to a long-term analysis (Wooldridge, 2010). The following section shows that temperature and climate variables can not obtain a long-term relationship. Consequently, this section will focus exclusively on the Autoregressive Vector [VAR] model, focusing on the Granger analysis.

The basis of this [VAR] model is that each of the system's time series influences the other. Hence, it is possible to predict the series in the system (Wooldridge, 2010). With the employment of Granger's analysis, it is possible to test this relationship even before building the model.

4.1 Granger analysis

This causality proves the null hypothesis that the coefficients of the values passed in the regression equation are zero. Then, the past values of the time series [*x*] do not cause the other series [*y*] (Ahmed et al., 2018). Therefore, if the p-value obtained from the test is less than the significance level of 0.05, then the null hypothesis can be safely rejected.

Granger causality was proposed by Granger (1969) and was first used in econometrics to identify the cause of causality between variables based on predictability theory. Recently, this method has spread to the climate system (Attanasio, 2012). The Granger-causal inference is that the variable *X* causes variable Y if the predictability of *Y* improves when *X* is taken into account. The Granger-causal method is suitable for stationary and linear systems.

In Granger's theory of causality, the coefficient of determination R^2 is introduced as an action to evaluate the forecast (Kuldosheva, 2021). R^2 can be interpreted as the fraction of variance explained by the forecast model and can be expressed as follows:

$$R^2\ (y,\hat{y}) = 1 - \frac{\sum_i^N = P+1 (y_i - \hat{y}_i)^2}{\sum_i^N = P+1 (y_i - \bar{y})^2}$$

where y represents the observed data; $\hat{y}$ is the predicted data, and P is the length of the lag.

5. Results

Table 1
Lag selection

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-296.82				22.49	8.79	8.81	8.85
1	-271.36	50.91*	4	0.00***	11.97*	8.16*	8.24*	8.35*
2	-269.69	3.35	4	0.50	12.82	8.23	8.36	8.55
3	-269.53	0.32	4	0.99	14.36	8.34	8.52	8.80
4	-268.87	1.32	4	0.86	15.87	8.44	8.67	9.02

*** significant at 1%

Table 2
Dickey-Fuller root test

Variable	Z(t)	p	1% Critical Value	5% Critical Value	10% Critical Value
Rain	-7.14	0.00	-3.55	-2.91	-2.59
Temperature	-3.48	0.01	-3.55	-2.91	-2.59

Table 3
Lag root test

Variable	D.	Coefficients	Standard Error	t	p>t	95% Confidence interval	
Rain	L1.	-1.47	0.21	-7.14	0.00	-1.87	-1.06
	LD.	0.00	0.12	-0.02	0.98	-0.24	0.24
	Constant	23.07	3.23	7.14	0.00	16.63	29.52
Temperature	L1.	-0.41	0.12	-3.48	0.00	-0.64	-0.17
	LD.	-0.10	0.12	-0.82	0.42	-0.35	0.14
	Constant	8.96	2.78	3.23	0.00	3.42	14.50

Table 4
Vector Auto Regression

Variable 1	Variables 2	Coefficients	Standard Error	t	p>t	95% Confidence interval	
Rain	Rain	-0.46	0.12	-3.81	0.00***	-0.70	-0.22
	Temperature	-0.01	0.00	-2.89	0.00***	-0.02	0.00
	Constant	22.23	4.99	4.45	0.00***	12.45	32.01
Temperature	Rain	9.63	4.00	2.41	0.02**	1.78	17.47
	Temperature	0.53	0.12	4.46	0.00***	0.30	0.76
	Constant	-81.42	164.90	-0.49	0.62	-404.63	241.79

*** significant at 1%, ** significant at 5%

Table 5
Granger analysis

Equation	Excluded	chi2	df	p>chi2
Rain	Temperature	9.21	4	0.06*
Rain	All	9.21	4	0.06
Temperature	Rain	7.21	4	0.13
Temperature	All	7.21	4	0.13

Table 6
Post-test analysis

Equation	RMSE	R2	Chi2	p>chi2
Rain	0.33	0.32	32.13	0.00***
Temperature	10.78	0.37	40.78	0.00***

*** significant at 1%

According to Table 1, the lag analysis suggested that lag number 1 was helpful for the subsequent test since it is significant at 1% and has good parameter scores, especially in the Akaike one. Table 2 shows the root analysis. Then, it was demonstrated that the variables were stationary at the level. Moreover, Table 3 shows that the variables have a stationary trend at lag one.

Due to the nature of the data, arranging a cointegration test was impossible. Therefore, the VAR analysis was executed. Then, Table 4 states that at lag one, there was a possible relationship between Rain and Climate change and between Climate change and rainfall level. Complementary Table 5 portrays that Climate Change had a causal relationship with rain. However, there was no evidence of a causal relationship between Climate Change on Rain.

The post-test analysis in Table 6 showed that the suggested Climate Change on Rain relationship had acceptable outcomes in the R2 index and was statistically significant.

5. Discussion

The analysis found a short-term relationship between climate change and rainfall. It was inverse since it is possible to state that the rainfall fall while the climate change expressed in the temperature increases. The possible relationship follows

Ncoyini & Savage (2022), who found a possible connection between the variables. However, Hoerling et al. (2010) stated that linking climate change with rainfall was impossible.

The sense of the relationship was found to be positive. Hence, this result agrees with Ilbay-Yupa et al.'s (2021)and Trenberth's (2011) findings. Nonetheless, it was not the positions of Al-Ansari et al. (2014)and Tarmizi et al. (2019). A possible explanation is the geographic surroundings of the analysis. Then, rainfall seems to be lowering in arid zones while increasing in tropical areas.

Furthermore, the results agree with the findings of Ncoyini & Savage (2022). Then, it is plausible that the relationship between climate change and rainfall keeps positive in the short term. Nonetheless, there is evidence that this trend might reverse in a long time.

6. Conclusion

The current research found a short-term relationship between climate change and temperature in the Pacaya Samiria national reserve. It is a rainforest zone which is located in the Amazonas. By using Granger analysis, it was possible to state that there was a negative causality of Climate Change on rainfall. Climate change is understood as the temperature increase due to anthropogenic causes, although some scientists do not share it.

Although the study differed from the analysis of arab researchers who found that climate change had a negative causality on rainfall, it is possible to state that rainforest zones have another trend. Then, climate change increases the rain with negative consequences to the surrounding areas because of the flooding.

Finally, it seems necessary to arrange more studies in different areas of Peru to assess the possible changes in the pattern for other regions. Moreover, data must be collected with more frequency to have updated trends.

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