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The Relationship between Forest Cover Loss and Annual Rainfall in the Departments of Peru, 2013-2022

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The relationship between forest cover loss and annual rainfall in the departments of Peru, 2013-2022

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ABSTRACT

Forest masses participate in the hydrological cycle and precipitation patterns. Therefore, the loss of these forest masses has significant implications for atmosphere-surface dynamics. The objective of this article is to determine the influence of forest cover loss on annual rainfall in the departments of Peru during the period 2013-2022. The methodology was quantitative, longitudinal non-experimental design, with panel data and a random-effects model was estimated. The results reveal a positive and statistically significant relationship between tree cover loss and total annual precipitation, specifically, a 1% increase in deforestation is related to an average increase of 0.186% in annual rainfall. The findings contrast with most previous evidence documenting reductions in precipitation due to deforestation, however, they are consistent with some studies. The research concluded that there is a positive relationship between the loss of forest cover and annual rainfall in the departments of Peru during the period studied.

1. Introduction

Forests are important in the global climate system because of their ability to regulate the hydrological cycle and precipitation patterns (Lawrence & Vandecar, 2015). In fact, land-use modifications have been found to contribute more than 20% of greenhouse gas emissions from human activity, and declining forest cover has various implications for the dynamics between land area and climate (Leblois, 2021). The decrease in forest cover generates alterations in the hydrological cycle and precipitation patterns through various mechanisms. One of them is evapotranspiration, a process by which liquid water is transferred to the atmosphere from land surfaces. Deforestation, on the other hand, causes changes in the roughness of the earth's surface, modifying the way air interacts with the soil. In addition, this phenomenon alters atmospheric circulation patterns, which are large-scale movements of air masses that influence climate and weather conditions (Shukla et al., 1990; Spracklen et al., 2012). The implications of deforestation on the hydrological cycle and precipitation patterns have been widely studied, although with mixed results. Some research has documented reductions in rainfall related to forest cover loss (Duku & Hein, 2023; Sampaio et al., 2021; Smith et al., 2023; Zemp et al., 2017). However, other studies suggest that, at certain spatial and temporal scales, deforestation could lead to an increase in rainfall (Duku & Hein, 2021; Liang et al., 2019). In the Peruvian context, deforestation in our country reached an alarming level of 203,272 hectares (ha), the highest figure recorded during the last two decades. Thus, between 2001 and 2020, there was a cumulative growth of 142% in deforestation, with an average annual increase of 4.8% (ComexPerú, 2021). Given the importance of forests for the hydrological cycle and climate variability in Peru, understanding the implications of forest cover losses at the departmental level is a priority. The objective of this article is to determine the influence of forest cover loss on annual rainfall in the Departments of Peru during the period 2013-2022. To this end, the article is organized by sections, in the first the introduction is presented, in the second the review of the literature, then the theoretical bases, methodology, results, discussion and conclusions.

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2. Literature review

The topic has been investigated from different perspectives, however, the understanding of changes in rainfall as a result of historical deforestation remains limited (Duku & Hein, 2023). Several studies have documented significant reductions in rainfall associated with deforestation. In the Amazon Zemp et al. (2017) In their study, they found that deforestation can reduce dry-season rainfall by up to 20%, eroding the resilience of forests. On a broader scale, Duku and Hein (2023) sought to analyze the cumulative impacts of historical deforestation on rainfall patterns across South America between 1982 and 2020. The results of the study indicated that, on average, accumulated deforestation reduced rainfall during the period 2016-2020 by 18% over deforested areas and 9% over non-deforested areas. throughout South America. In addition, with respect to the most recent deforestation, a period between 2000 and 2020, they found that it has reduced rainfall during the period 2016-2020 by 10% on deforested areas and by 5% on non-deforested areas. In a pan-tropical analysis, Smith et al. (2023) conducted an assessment of the impacts of forest loss on rainfall between 2003 and 2017. The results revealed reductions in rainfall at scales greater than 50 km, with the largest decreases (0.25 ± 0.1 mm per month) being 200 km for every 1% of forest loss. Likewise, in a research carried out by Sampaio et al. (2021) in order to systematically compare the physiological effects of eCO2 plants and deforestation on rainfall in the Amazon. The authors found decreases in average annual precipitation for the two scenarios (Physiology orβ: 12 %; Deforestation: 9%) which are well above the interannual variability of precipitation in the Amazon of 5%. In India, Anjali and Roshni (2022) They set out to analyze the impact of forest cover change on meteorological parameters such as precipitation and land surface temperature, 2000-2019. The results indicate a precipitation breakpoint for 2008 and at 47 m elevation (MSL) off the coast of the Arabian Sea. On the other hand, some studies suggest that deforestation could lead to increases in rainfall under certain conditions. In Africa, Duku and Hein (2021) set out to assess the impacts of various deforestation scenarios on rainfall patterns in sub-Saharan Africa. The results showed that, in the presence of complete deforestation, rainfall in deforested areas would be greatly reduced. However, total deforestation would slightly increase rainfall in some parts of southern Africa and decrease it in others. In the same vein, Liang et al. (2019) To identify the relationship between tree cover removal and rainfall in two large areas of Australia between 1979 and 2015. The results mainly showed a positive relationship between tree cover and precipitation in (value-p< 0.1) in the New South Wales/Victoria region. In addition, deforestation in forest cover and the regulation of water flows have been studied. Hall et al. (2022) They sought to examine the role of forest cover. in the regulation of the synchronization and volume of the flow in Costa Rica between 2005-2016. The results indicated that watersheds with high forest cover consistently had higher low and maximum flows than those deforested under all rainfall conditions. On the other hand, other research analyzes the relationship in the opposite direction. For example, in the research of Leblois (2021) The aim was to pinpoint the impact of seasonal rainfall quality on deforestation by combining annual tree cover loss, land cover, human activity, and daily rainfall data obtained using high-resolution remote sensing. The results revealed that, in areas with significant forest cover, a short rainy season causes a 15% increase in deforestation, while in disconnected areas with small proportions of cropped area, the increase in deforestation reaches 20%.

2. Theoretical basis

The phenomenon of deforestation, defined as the permanent conversion of forested areas to other land uses, has been widely recognized as an influencing factor in the hydrological cycle (Shukla et al., 1990; Spracklen et al., 2012). Forest masses they participate in the hydrological cycle due to their ability to intercept, evapotranspire and regulate water flows (Ellison et al., 2017). Therefore, when forest cover is removed, there is a decrease in evapotranspiration, with potential implications for cloud formation and, therefore, precipitation (Lawrence & Vandecar, 2015). According to Baudena et al. (2021), in the Amazon, in the Amazon region, changes in land use carry certain implications, the magnitude of which has not been fully understood in the current scientific literature. The Amazon rainforest contributes to increased precipitation levels on a regional scale, because trees absorb water from the soil and release it into the atmosphere through the process of transpiration. Existing forests are also making a critical contribution to addressing the impacts of climate change, not only by absorbing greenhouse gases, but also by creating more resilient landscapes. They achieve this through the regulation of water flow, the improvement and maintenance of soils for agricultural activity, and the protection of coastal communities from extreme weather events and sea level rise, as well as the preservation of migratory corridors for flora and fauna (World Bank [WB], 2016). In addition, deforestation alters atmospheric circulation patterns at regional and global scales, which in turn affects the distribution and intensity of rainfall (Costa & Foley, 2000; Gedney & Valdes, 2000). The effects of forest cover loss can be even more complex when considering the interaction between deforestation and other factors such as climate change, urbanization, and natural variability of the climate system (Pielke et al., 2007; Seneviratne et al., 2006). However, the relationship between deforestation and precipitation is complex and can vary depending on the spatial and temporal scale, as well as the specific climatic and geographical conditions of a given region (Duku & Hein, 2023). In fact Milici et al. (2020) They argue that the mechanisms on which the presence of larger tree tracts impact annual precipitation lack clarity.

3. Methodology

This research is developed under a quantitative approach, since time series and statistical procedures are used to analyze the relationship between forest cover loss and annual rainfall in the departments of Peru during the period 2013-2022. The choice of this approach is based on the numerical nature of the data and the need to obtain results (Ñaupas et al., 2018). Likewise, the design is non-experimental longitudinal panel data because it seeks to analyze the relationship of the variables over time (Hernández-Sampieri & Mendoza, 2018). In addition, the use of dashboard data makes it possible to control for unobservable heterogeneity between departments and achieve more accurate estimates (Gujarati & Porter, 2009). Data on tree cover loss, measured in thousands of hectares, is obtained from the Global Forest Watch website, an online platform that provides data to monitor forests around the world. On the other hand, the total annual precipitation data, measured in millimeters, are obtained from the website of the National Institute of Statistics and Informatics (INEI). The sample is made up of 20 departments of Peru: Amazonas, Ancash, Apurímac, Arequipa, Ayacucho, Cajamarca, Cusco, Huancavelica, Huánuco, Junín, La Libertad, Lambayeque, Loreto, Madre de Dios, Pasco, Piura, Puno, San Martín, Tumbes and Ucayali. The departments were selected for the availability of complete data for the variables of interest during the study period. The inferential analysis is carried out through a panel data model, which allows capturing the unobservable heterogeneity between individuals (departments) and over time. For the estimation of the model, the variables are transformed into logarithms in order to obtain elasticities, that is, to interpret the coefficients as percentage changes in the dependent variable in the face of percentage changes in the independent variables (Gujarati & Porter, 2009). The model estimator is determined through statistical tests, first, the F-test to assess the significance of fixed effects, then, the Breusch and Pagan Lagrange multiplier test to determine the presence of random effects, and finally, the Hausman test to decide between a fixed-effect or random-effects model. After the estimation of the model, the fulfilment of the basic assumptions, such as homoscedasticity and the absence of autocorrelation, is verified.

4. Results

In the first instance, a descriptive analysis of the variables is carried out. Table 1 presents the descriptive statistics of the variable loss of tree cover and total annual precipitation for the departments. The variable loss of tree cover shows a general average of 11.45745 thousand hectares, and a standard deviation of 16.024. Between groups, the variation (15,939) is greater than the variation within the groups (3,750), denoting greater heterogeneity in tree cover loss between departments than over time within each department.

Table 1
Descriptive statistics

Variable	Detail	Media	Standard deviation	Minimal	Maximum	Remarks
Loss of tree cover	General	11.45745	16.024	0.000	62.951	N= 180
	Between groups		15.939	0.004	50.491	n= 20
	Within the groups		3.750	-3.157	26.508	T= 9
Total annual precipitation	General	907.6388	775.677	9.800	3282.200	N= 180
	Between groups		773.327	25.022	3010.394	n= 20
	Within the groups		174.264	141.333	1537.133	T= 9

Note. Own elaboration.

The average annual rainfall is 907.6388 millimeters, with a standard deviation of 775.677. The general minimum value is 9,800 and the maximum is 3282,200 millimeters. The variation between groups (773,327) is greater than the variation within the groups (174,264), i.e., there is greater heterogeneity in precipitation levels between departments than over time within each department. Table 2 presents the correlation between the variables, indicating that there is a positive correlation of 0.759 between total annual precipitation and loss of tree cover, that is, there is a linear relationship of medium and direct magnitude between both variables, indicating that the departments with greater loss of tree cover tend to have higher levels of total annual precipitation. and vice versa.

Table 2
Correlation between variables

Variable	Total annual precipitation	Loss of tree cover
Total annual precipitation	1	
Loss of tree cover	0.759	1

Note. Own elaboration.

Table 3 presents the results of the statistical tests used to select the most appropriate estimator for the panel data model. The first test is the Breusch-Pagan test, with a statistic of 591.46 and a p-value of 0.000 showing the presence of random effects in the model. In that sense, there is significant variation between departments that cannot be captured by a pooled regression model, which does not take into account the dashboard structure of the data. The second test is the F-test, which tests the null hypothesis that all individual effects are equal to zero, i.e., that there are no significant differences between departments. The F statistic of 96.55 and the p-value of 0.000 allow the null hypothesis to be rejected. Finally, the Hausman test is used, whose null hypothesis mentions that individual effects are not correlated with the explanatory variables, and presents a Hausman statistic of 1.31 and the p-value of 0.252 do not reject this null hypothesis, therefore, the random-effects model is more appropriate than the fixed-effect model.

Table 3
Tests for estimator selection

Test	Statistical	p-value
Breusch-Pagan	591.46	0.000
Exhibit F	96.55	0.000
Hausman's Test	1.31	0.252

Note. Own elaboration

Table 4 presents the results of the random-effects model that estimates the relationship between the logarithm of tree cover loss and the logarithm of total precipitation. The estimated coefficient for the logarithm of tree cover loss is 0.186, with a standard error of 0.039, statistically significant at 5%, *therefore*, there is a positive and significant relationship between tree cover loss and total annual precipitation. *Specifically*, a 1% increase in tree cover loss is associated with an average 0.186% increase in total annual precipitation. However, the relationship between deforestation and precipitation is complex and varies according to spatial and temporal scales. The positive relationship between deforestation and precipitation is based on several reasons, including deforestation is likely to alter the local hydrological cycle by reducing evapotranspiration and the soil's water-holding capacity, sometimes leading to an increase in surface runoff and, consequently, an increase in precipitation). In addition, deforestation often modifies the roughness of the earth's surface and alters local atmospheric circulation patterns, influencing cloud formation and precipitation. On the other hand, there are other variables not included in the model (specification bias) that can influence the relationship obtained in the estimation through random effects.

Table 4
Model estimated through random effects

Logarithm of total annual precipitation	Coefficient
Logarithm of tree cover loss	0.186**
	(0.039)
Constant	6.124**
	(0.276)
R-Square	
Within groups	0.085
Between groups	0.337
Global	0.310
Number of observations	178
Number of groups	20
Observations by group	9
Wald chi2(3)	22.44
Prob > chi2	0.000

Note. Own elaboration. ** denotes significance at 5%. Standard errors are presented in parentheses.

The model's global statistics, including R-squared within or within groups (0.085) indicate that 8.5% of the variation in the logarithm of total annual precipitation within each department over time is explained by the logarithm of tree cover loss, while R-squared between or between groups (0.337), indicates that 33.7% of the variation in the logarithm of total annual precipitation between departments is explained by the logarithm of tree cover loss. The overall R-squared (0.310) indicates that 31% of the total variation in the logarithm of total annual precipitation is explained by the model. In addition, the model at the global level is significant with a Wald chi2 of 22.44 and a significance level of 0.000, below the threshold of 5%. The estimated model is subjected to assumption verification, and as it is a random-effects model, there is no known test for heteroskedasticity as in the fixed effects, therefore, only autocorrelation is verified, and the Sosa-Escudero and Bera test is used for autocorrelation. The results indicate that there is no evidence of autocorrelation in the errors of the model. Thus, the estimates obtained are efficient and consistent.

Table 5
Sosa-Escudero and Bera test for autocorrelation

Test	Statistical	P value
Serial Correlation	2.78	0.0952
Random Effects		
Two tails	425.68	0.000
A queue	0.63	0.000
Joint Testing	594.24	0.000

Note. Own elaboration.

5. Discussion

The random-effects model revealed a positive and statistically significant relationship between tree cover loss and total annual rainfall in the departments of Peru during the period 2013-2022. The coefficients quantify that a 1% increase in tree cover loss is associated with an average increase of 0.186% in total annual precipitation. Thus, the results show that deforestation is related to an increase in precipitation levels in the analyzed sample. The support for this relationship indicates that one of the main mechanisms by which deforestation increases rainfall is through the reduction of evapotranspiration. Thus, forests, with their extensive leaf area, are large consumers of water through transpiration. Therefore, by removing forest cover, evapotranspiration is reduced, causing a greater amount of precipitated water to remain on the earth's surface, increasing surface runoff and, potentially, soil moisture and groundwater recharge. However, the findings do not agree with several previous studies that show reductions in precipitation associated with deforestation. Among them, Zemp et al. (2017) found that in the Amazon, deforestation reduces rainfall in the dry season by up to 20%, eroding the resilience of the remaining forests. In the same vein, Duku y Hein (2023), in an analysis at the level of South America, found that accumulated deforestation from 1982 to 2020 decreased rainfall by 18% over deforested areas and by 9% over non-deforested areas during 2016-2020. They also contrast with what was found by Smith et al. (2023), who reported sharp reductions in rainfall at scales greater than 50 km associated with forest loss in a pantropical analysis. In addition to this, they do not agree with Sampaio et al. (2021), who found 12% decreases in annual precipitation for an Amazon deforestation scenario. On the other hand, the findings agree with what was stated by Duku y Hein (2021), authors who found that total deforestation would slightly increase rainfall in southern Africa, but decrease it in other regions of the continent. Hence, the complexity of the processes involved implies that the deforestation-precipitation relationship can vary depending on the spatial scale, local climate, and other factors. Theoretically, forests actively participate in the water cycle by intercepting, evapotranspiring, and regulating water flows (Ellison et al., 2017). Therefore, its removal could significantly alter this cycle and the atmosphere-surface dynamics. However, the precise effects depend on factors such as the characteristics of deforestation, the prevailing climatic conditions, the topography and the spatial scale considered (Lawrence & Vandecar, 2015; Shukla et al., 1990).

6. Conclusion

The objective of this article was to determine the influence of forest cover loss on annual rainfall in the departments of Peru during the period 2013-2022. The findings obtained through the analysis of panel data reveal a positive and statistically significant relationship between both variables. Specifically, the estimated model indicates that a 1% increase in tree cover loss is associated with an average increase of 0.186% in total annual precipitation in the Peruvian departments analyzed. Therefore, higher levels of deforestation are consistent with an increase in rainfall in the context analyzed during the study period. While these findings contrast with several previous studies that have documented reductions in precipitation associated with deforestation, the results are consistent with some studies that have found positive relationships at certain spatial and temporal scales.

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