

Journal of Agrometeorology

ISSN: 0972-1665 (print), 2583-2980 (online) Vol. No. 26 (4): 425-430 (December - 2024) https://doi.org/10.54386/jam.v26i4.2687 https://journal.agrimetassociation.org/index.php/jam



Research Paper

Trend analysis and change-point detection of temperature and rainfall in southern Peruvian Amazon and its relation to deforestation

ANDREA AUCAHUASI-ALMIDON^{1*}, CARLOS CABRERA-CARRANZA² and JORGE GARATE-QUISPE³

- ¹Universidad Nacional Mayor de San Marcos. Facultad de Ingeniería Geológica, Minera, Metalúrgica y Geográfica. Lima 150101, Peru.
- ²Universidad Nacional Mayor de San Marcos. Facultad de Ingeniería Geológica, Minera, Metalúrgica y Geográfica, Departamento Académico de Ingeniería Geográfica. Lima 150101, Peru.
- ³National Amazonian University of Madre de Dios. Academic Department of Forestry and Environmental Engineering. Puerto Maldonado 17001, Peru.

ABSTRACT

The study aimed to identify the change points, tendencies, and trends in climatic parameters (precipitation and temperatures) and to investigate their relationship with deforestation in the southeastern Peruvian Amazon (Tambopata). Rainfall and temperature data for the Puerto Maldonado station from 1970 to 2023 was used. Monthly, seasonal, and annual precipitation as well as temperature (maximum, minimum, and mean) were analyzed for possible trends using nonparametric Mann-Kendal statistic test, while the Pettitt test was employed to detect the abrupt change point in time series. The Spearman's correlation coefficient was used to identify the relationship between deforestation and climate parameters. The results revealed a rise in mean, minimum, and maximum temperatures. Mann Kendall and Sen's slope revealed significant trends in the monthly, seasonal and annual temperatures in the study period. However, in contrast to the temperature variation trend, the monthly, seasonal and annual precipitation did not present a significant trend. Significant positive correlations were obtained between deforestation and temperatures but its association with precipitation was not significant.

Keywords: Change point, climate change, climate variability, deforestation, Tambopata, Madre de Dios.

Aerosol emissions, deforestation and other human activities have increased during the second half of the 20th century, increasing the frequency of extreme events such as increased heat waves, frequent droughts, and flooding, which have affected human populations and the global ecosystem. Likewise, the change generates other severe impacts on the environment such as increased extreme flows, fires, forest loss, water depletion and loss of ecosystem services. In addition, global climate change affects food security, water, health and housing for human populations (Fattah et al., 2024; Swami, 2024; Umeh and Gil-Alana, 2024). Trend studies analyze changes over time in a specific climate variable e.g., temperature, precipitation and drought (Da Silva et al., 2019). The nonparametric Mann-Kendall test is widely used for trend analysis because it is robust to outliers, missing values and can be used for seasonal or cyclic data (Espinoza et al., 2009; Sridhara and Gopakkali, 2021). Likewise, the World Meteorological Organization has used the Mann-Kendall test in climate trend studies (Espinoza et al., 2009; Fattah et al., 2024; Lavado et al., 2012).

Temperature and precipitation are considered the main indicators for investigating global climate change (Lute and Abatzoglou, 2021). Nevertheless, deforestation and fires that occur in the Amazon have potential impacts on land surface temperature and rainfall variability (Reygadas *et al.*, 2023; Silva *et al.*, 2023). In the southeastern Peruvian Amazon (Madre de Dios), agriculture, gold-mining and selective logging cause negative impacts on biodiversity and ecosystem services in forest ecosystems, and they are considered major drivers of deforestation (Lagneaux *et al.*, 2024). Although, gold-mining causes the most severe negative impacts on ecosystems (Pisconte *et al.*, 2024), agriculture drives the highest proportion of deforestation (Alarcón-Aguirre *et al.*, 2023). Therefore, in the current context of global warming and

Article info - DOI: https://doi.org/10.54386/jam.v26i4.2687

Received: 9 August 2024; Accepted: 17 September 2024; Published online: 01 December 2024

"This work is licensed under Creative Common Attribution-Non Commercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) © Author (s)"

^{*}Corresponding author's email: andrea.aucahuasi@unmsm.edu.pe

biodiversity crisis, deforestation in the Amazon is a major global concern due to its impacts on climate, the natural environment, and the socioeconomic conditions of the most vulnerable populations (Cabral et al., 2024). On the other hand, recent studies have demonstrated how deforestation in the Amazon can drastically affect climatic variables. The surface temperature increases as deforestation progresses (Maillard et al., 2022) but the precipitation tends to decrease (Reygadas et al., 2023). However, little is known about how forest degradation can affect precipitation and temperature at local scales. This is because climate studies have covered large areas and analyzed trends on a global scale, but to understand climate change it is essential to study at the local scale (Restrepo-Coupe et al., 2023). In Madre de Dios, to our knowledge there are limited studies on trends and change points of precipitation and temperature at local and long-term scales. Therefore, considering the impacts of anthropogenic activities on climate variability, it is important to understand the relationship between deforestation, precipitation and temperature.

The objectives of the study were to (i) evaluate temporal trends and magnitude of annual, seasonal and monthly rainfall and temperature during 1970–2023 in the southeastern Peruvian Amazon; (ii) detect an abrupt change point of rainfall and temperatures; and (ii) identify the effects of deforestation on climatic variables.

MATERIALS AND METHODS

Study area

The study area is Puerto Maldonado, which is located in the southwest Peruvian Amazon, Tambopata, Madre de Dios. Madre de Dios is considered Peru's capital of biodiversity due to high levels of cultural and biological diversity within its Amazonian ecosystems (Saatchi *et al.*, 2011). The study area has a seasonal climate, with a marked dry season from June to September, months with less than 100 mm/month (dry-season precipitation) (Restrepo-Coupe *et al.*, 2023). The study area has a tropical, warm, and humid climate. The mean total annual precipitation between 1970 and 2023 was 2257 mm (ranging from 1413 to 3734), and the rainy season is typically between November and April (>250 mm/month). The average annual temperature is 27.7 °C (ranging from 16 and 33.8 °C). However, cold spells in Puerto Maldonado could produce an average minimum temperature drop of 8 °C.

Data sources

We used the monthly precipitation (mm) and monthly average data of maximum (Tmax), minimum (Tmin) and mean temperatures (Tmean) (°C) provided by the Peruvian Meteorological and Hydrological Service (SENAMHI) for the Puerto Maldonado meteorological station (12°35′1" S, 69°12′1" W, and 200 m a.s.l.), for a period of 53 years (1970–2023). The deforestation data at the study site between 1985 and 2023 was obtained from MapBiomas Collection 7 (https://amazonia.mapbiomas.org). MapBiomas produces annual land cover/use maps from a pixel-by-pixel classification of the Landsat satellite images using machine learning algorithms on the Google Earth Engine platform.

Trends and change point detection

Monthly, seasonal and annual precipitation and

temperature trends were analyzed using the Mann-Kendall (MK) (Kendall, 1975). MK is a non-parametric test, that has no prerequisite conditions for the data to be normally distributed (Swami, 2024; Uwizewe *et al.*, 2024). The change per unit time (slope magnitude) was determined using Sen's slope estimator (Sen, 1968). The non-parametric Pettitt's test was used to detect change points in climate data without any assumption about the distribution of the data (Pettitt, 1979).

The "trend" package of the R software (https://www.r-project.org) was used to detect trends, change points and slope magnitude in the time series of precipitation, Tmax, Tmean and Tmin.

Data analysis

Annual, monthly and seasonal precipitation and temperature data for 54 years (1970-2023) were analyzed. The seasonal variability of precipitation and temperature were analyzed in quarterly groupings: December-January-February (Summer), March-April-May (Autumn), June-July-August (Winter), and September-October November (Spring). Spearman's correlation coefficient was used to analyze the relationship between deforestation and climate variables because the data do not comply with assumptions about the distribution of the data. R software version 4.4.0 and SigmaPlot v15 were used to perform the analysis and figures at a significance level of 0.05.

RESULTS AND DISCUSSION

Precipitation trends

Trends (Sen's slope; p > 0.05) and change points were not significant (Pettit's test; p > 0.05) in monthly, annual and seasonal precipitation (Table 1) during the study period (1970-2023). Although, precipitation has shown a non-significant decreasing trend in January, February, March, July, August, September and in all seasons of the year. The non-existence of significant trends and change points in annual precipitation found in the present study are consistent with those reported by previous studies (Almeida et al., 2016; Espinoza et al., 2010; Lavado et al., 2012; Sridhara and Gopakkali, 2021). Espinoza et al., (2010) and Almeida et al., (2016) found a non-significant decrease in annual precipitation in the Amazon Basin between 1975-2003, and in the Peruvian Amazon between 1973 and 2013, respectively. In addition, Lavado et al., (2012) found non-significant trends in annual and monthly precipitation in the Amazon Basin between 1965 and 2007. However, the results about seasonal and monthly precipitation trends differ from those reported by previous studies (Espinoza et al., 2009; Lavado et al., 2012). In the Amazon basin, during the 1975-2003 period, Espinoza et al., (2009) observed that the precipitation decreased in winter, spring, January and February, June, July, August, September, October, November and December. Deforestation of tropical forests may cause precipitation reductions (Smith et al., 2023). In the Brazilian Amazon, De Souza et al., (2023) found that annual precipitation decreased due to the loss of forest cover between 1982 and 2020, while Silva et al., (2023) found a decrease in the precipitation volume due to severely increased deforestation between 2001 and 2020.

Table 1: Results of the statistical tests (Mann–Kendall, Pettitt and Sen's slope) for annual, seasonal and monthly precipitation and temperatures over the period 1970–2023.

| Period | Mean temperature | | | Maximum temperature | | | Minimum temperature | | | Precipitation | | |
|--------|------------------|---------|-----------|---------------------|---------|-----------|---------------------|---------|-----------|---------------|------|-----------|
| | $Z_{\rm s}$ | Pet | Q_{med} | $Z_{\rm s}$ | Pet | Q_{med} | $Z_{\rm s}$ | Pet | Q_{med} | $Z_{\rm s}$ | Pet | Q_{med} |
| Summer | 4.25** | 2004** | 0.026** | 3.49** | 1997** | 0.031** | 3.19** | 2010** | 0.033** | -0.84 | 1988 | nd |
| Autumn | 4.99** | 2004** | 0.029** | 3.28** | 1998** | 0.025** | 3.76** | 2010** | 0.038** | 0.46 | 1978 | nd |
| Winter | 4.95** | 2000** | 0.046** | 3.55** | 2000** | 0.037*** | 5.06** | 2002** | 0.059** | -0.31 | 1975 | nd |
| Spring | 4.99** | 2003** | 0.041** | 3.80** | 1996** | 0.037* | 3.60** | 2008** | 0.043** | -0.72 | 2003 | nd |
| Annual | 5.68*** | 2003*** | 0.036*** | 4.36*** | 1997*** | 0.031*** | 4.36*** | 2010*** | 0.048*** | -0.37 | 1986 | nd |
| Jan | 3.72*** | 2004** | 0.023*** | 3.12** | 1997*** | 0.030*** | 2.45* | 2010** | 0.027* | -1.42 | 1988 | nd |
| Feb | 2.91** | 2004*** | 0.022** | 2.49* | 1997*** | 0.023* | 2.63** | 2010*** | 0.035** | -0.52 | 1986 | nd |
| Mar | 3.58*** | 2004*** | 0.024*** | 2.58** | 1998*** | 0.022** | 2.81** | 2010** | 0.032** | 0.01 | 1984 | nd |
| Apr | 4.45*** | 2004*** | 0.033*** | 3.67*** | 1998*** | 0.037** | 3.46*** | 2010*** | 0.037*** | 0.18 | 2015 | nd |
| May | 4.70*** | 2000*** | 0.033*** | 2.36* | 1998*** | 0.022* | 3.50*** | 2010** | 0.042*** | 1.06 | 1977 | nd |
| Jun | 3.95*** | 2000*** | 0.041*** | 2.10* | 2000** | 0.026* | 4.01*** | 2003*** | 0.054*** | 0.17 | 1993 | nd |
| Jul | 3.88*** | 2000*** | 0.052*** | 2.63** | 2000*** | 0.038** | 4.48*** | 2000*** | 0.066*** | -0.21 | 1978 | nd |
| Aug | 4.98*** | 1999*** | 0.058*** | 4.18*** | 1998*** | 0.053*** | 4.85*** | 2003*** | 0.053*** | -1.49 | 1977 | nd |
| Sep | 4.95*** | 2003*** | 0.054*** | 3.79*** | 1996*** | 0.047*** | 4.93*** | 2003*** | 0.068*** | -0.6 | 1992 | nd |
| Oct | 4.39*** | 2008*** | 0.039*** | 3.60*** | 1997*** | 0.037*** | 4.26*** | 2008*** | 0.055*** | -0.26 | 1994 | nd |
| Nov | 3.54*** | 2003*** | 0.025*** | 2.60** | 1994** | 0.027** | 2.69** | 2008*** | 0.035** | 0.63 | 2013 | nd |
| Dec | 4.72*** | 2003*** | 0.032*** | 4.24*** | 1996*** | 0.036*** | 3.26** | 2008*** | 0.034** | 0.73 | 1991 | nd |

 $\overline{Z_s}$: Mann-Kendall test. Pet_u: Pettit's test (U) test. Q_{med} : Sen's slope estimator. * p < 0.05; ** p < 0.01; *** p < 0.001. nd = No trend.

Temperature trends

Maximum, minimum, mean temperatures showed a significant rising trend for annual, seasonal and all months (Sen's slope p < 0.05; Table 1). The annual mean temperature showed a significant increasing trend (0.036 °C year -1), and a change point was estimated in 2003 (Pettit's test, p < 0.01). The increase in the seasonal mean temperature was higher in winter (0.046 °C year -1) and spring (0.041 °C year -1). The change points for the seasonal mean temperature were detected between 2000 and 2004 (Pettit's test p < 0.01). Winter was the first season to present a change point (2000), while summer and autumn experienced a change point in 2004 (Pettit's test p < 0.01; Table 1). The existence of significant trends and change points in mean annual and seasonal temperature found in the present study are consistent with those reported by previous studies in the Amazon (Lavado et al., 2012; Malhi and Wright, 2004). The slopes of the mean annual and seasonal temperatures were more than four times higher than those reported by previous studies in the Amazon (Lavado et al., 2012; Malhi and Wright, 2004). Despite of the change point varied in more than 20 years, Malhi and Wright (2004) found a change point in 1970, and Lavado et al., (2012) found a change point in 1978.

The annual minimum temperature showed a significant increasing trend (0.048 °C year⁻¹), and a change point was estimated in 2010 (Pettit's test, p < 0.01). The increase in the seasonal minimum temperature was higher in autumn (0,059 °C year⁻¹), while in summer (0.038 °C year⁻¹) and spring were the lowest (0.033 °C year⁻¹). The change points for the seasonal minimum temperature were detected between 2002 and 2010 (Pettit's test, p < 0.01). Winter was the first season to present a change point (2002), while summer and autumn experienced a change point in 2010 (Pettit's test, p < 0.01; Table 1).

Our findings are different from the results reported in Lavado *et al.*, (2012), because they did not detect significantly decreasing trends from 1965 to 2007. However, the positive minimum temperature trends reported in the present study are in agreement with studies conducted in the southwestern Brazilian Amazon (Almeida *et al.*, 2016; Marengo and Camargo, 2008). Even though, the slopes of the minimum annual temperature were greater than 1.5 times, between 1.6 and 7 times, those reported by Marengo and Camargo (2008) (0.008 °C year¹) and Almeida *et al.*, (2016) (0.04 °C year¹).

The maximum temperature had a similar pattern and trend to that observed in the mean and minimum temperatures. The annual maximum temperature showed a significant increasing trend (0.031 °C year ⁻¹), and a change point was estimated in 1997 (Pettit's test p < 0.01). The increase in the seasonal maximum temperature was higher in winter and spring (0.037 °C year -1), while the lowest was in autumn (0.025 °C/year). The change points for the seasonal maximum temperature were detected between 1996 and 2000 (Pettit's test, p < 0.01). Spring was the first season to present a change point (1996), and the last one was winter (2000) (Pettit's test, p < 0.01; Table 1). Positive maximum temperature trends reported in the present study are in agreement with studies conducted in the Amazon region (Almeida et al., 2016; Marengo and Camargo, 2008). Although, the rates of seasonal and monthly maximum temperature increases were smaller than those in previous studies, Marengo and Camargo (2008), and Almeida et al., (2016) found a 30% greater increase in annual maximum temperature than in the present study. However, for seasonal maximum temperature our findings were different from the results reported in Marengo and Camargo (2008) because the slope of the annual temperature was two times greater and the increase in the summer was much higher than those found in the present study.

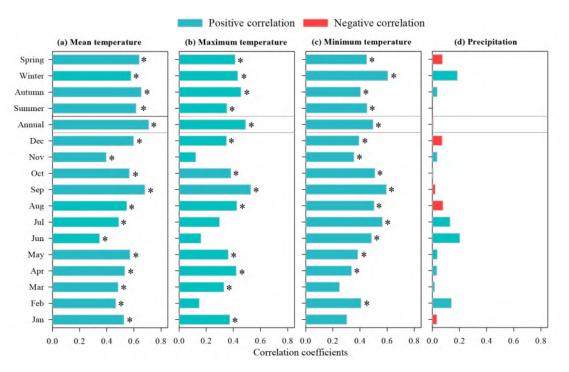


Fig. 1: Results of Spearman's correlation analysis between deforestation and climate variables (temperature and precipitation). Barplots represent the absolute values of Spearman's correlation coefficient. Asterisks represent significant correlations (p < 0.05). Red bars mean negative correlations and green bars positive correlations.

Relationships among deforestation, temperature and precipitation

The results showed that deforestation was positively correlated (rho > 0.3; p<0.05) with the seasonal and annual temperatures (Tmin, Tmax and Tmean) (Fig. 1). However, the relationship between deforestation and monthly temperatures varied slightly depending on the month. Deforestation was significantly and positively correlated with the all-month mean temperature (rho > 0.3; p < 0.05; Fig. 1a). A positive relationship between deforestation and maximum temperature was found in all months, but only relationships in January, March, April, August, September and December were statistically significant (rho > 0.3; p < 0.05; Fig. 1b). Deforestation was significantly and positively correlated with all month's minimum temperatures, except for January and March (rho > 0.3; p < 0.05; Fig. 1c). On the other hand, no significant correlation was found between deforestation and all precipitations (monthly, seasonal and annual) (p > 0.05; Fig. 1d). These results corroborate and indicate the potential effects of deforestation on surface temperature in the southeastern Peruvian Amazon.

Changes in climatic variables are related to changes in forest cover (Bakr *et al.*, 2024). The result of this study shows a low to moderate positive correlation between deforestation and temperature. These findings are in agreement with studies conducted in the Amazon region (Layza and Gonzales, 2018; Maillard *et al.*, 2022; Mesia, 2015; Silva *et al.*, 2023), who demonstrated that deforestation in the Amazon increases the temperature. In the Peruvian Amazon, Layza and Gonzales (2018) and Mesia (2015) found high variability explained ($r^2 > 0.6$) by deforestation in temperature increases in the departments of San Martin and Iquitos.

This highlights the negative impacts that deforestation may have on temperature and conservation in the Peruvian Amazon region (Layza and Gonzales, 2018). Although it is observed that the southwestern Amazon portion of the Amazon still conserves its native forest (Silva et al., 2023), our study draws the attention to reduce deforestation trends in Madre de Dios and thus reduce its potential negative effects on surface temperature. Therefore, the local society and public authorities need to have and implement public policies (Silva et al., 2023) aimed at environmental conservation of Madre de Dios and to try to stop the advances in agriculture, mining and forestry industry. This can be achieved with public policies oriented to territorial planning, promoting forest restoration, monitoring deforestation and climate variables at different scales (Maillard et al., 2022).

In the present study, deforestation was not significantly associated with precipitation, which differs from previous studies (De Souza *et al.*, 2023; Maillard *et al.*, 2022; Silva *et al.*, 2023). Maillard *et al.*, (2022) reported that deforestation tends to decrease precipitation in the Bolivian Amazon. In the Brazilian Amazon, De Souza *et al.*, (2023) found that annual precipitation decreased (6.6 to 9.9% less) due to the reduction of forest cover between 1982 and 2020 in Mato Grosso, and (Silva *et al.*, 2023) found a reduction in precipitation volume due to a severe increase in deforestation between 2001 and 2020 in Northern Brazil. These differences between our results and previous studies are because deforestation may also shift precipitation patterns (Smith *et al.*, 2023). In the study area, an increase in the dry season, decrease precipitation in summer and increase precipitation in the winter season was observed.

CONCLUSIONS

Our study represents the first to provide evidence-based field data about the relationship between deforestation and surface temperatures at the local scale in the southeastern Peruvian Amazon. We found a rise in mean, minimum, and maximum temperatures. Mann Kendall and Sen's slope revealed significant trends in the monthly, seasonal and annual temperatures (mean, minimum, and maximum) in the study period. In contrast to the temperature variation trend, the monthly, seasonal and annual precipitation did not present a significant trend during 1970–2023. On the other hand, the result of this study shows a low to moderate positive correlation between deforestation and temperature. However, deforestation was not significantly associated with precipitation.

ACKNOWLEDGEMENT

We thank National Service of Meteorology and Hydrology of Peru (SENAMHI) for providing the data for analysis of the study; and Alejandro Alcántara Boza, Oscar Tinoco Gómez and Elmer Benites Alfaro for useful comments on an earlier version of the manuscript.

Conflict of Interests: The authors declare that there is no conflict of interest related to this article

Funding: Not applicable.

Data availability: Data will be provided by author on request.

Authors contribution: A. Aucahuasi-Almidon: Conceptualization, Methodology, Data Curation, Formal analysis, Visualization, Writing - Original Draft, Writing - Review & Editing; C. Cabrera-Carranza: Writing - Review & Editing, Supervision; J. Garate-Quispe: Methodology, Conceptualization, Formal analysis, Writing - Original Draft, Writing - Review & Editing.

Disclaimer: The contents, pinions, and views expressed in the research communication published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

- Alarcón-Aguirre, G., Sajami, E., Vásquez, T., Ponce, L. V., Ramos, D., Rodríguez- Achata, L. and Garate-Quispe, J. (2023). Vegetation dynamics in lands degraded by gold mining in the southeastern Peruvian Amazon. *Trees, For. People*, 11:100369. https://doi.org/10.1016/j.tfp.2023.100369
- Almeida, C., Oliveira, J., Delgado, R., Cubo, P. and Ramos, M. (2016). Spatiotemporal rainfall and temperature trends throughout the Brazilian Legal Amazon, 1973-2013. *Int. J. Climatol.*, 37(4): 2013–2026. https://doi.org/10.1002/joc.4831
- Bakr, D., Al-Khalidi, J. and Hamid, B. (2024). Climate changes impact on the distribution of vegetation in Wasit and Nineveh

- regions of Iraq. *J. Agrometeorol.*, 26(1): 87-91. https://doi.org/10.54386/jam.v26i1.2417
- Cabral, B., Yanai, A., Graça, P.M. de A., Escada, M., de Almeida, C.M. and Fearnside, P.M. (2024). Amazon deforestation: A dangerous future indicated by patterns and trajectories in a hotspot of forest destruction in Brazil. *J. Environ. Manage.*, 354: 120354. https://doi.org/10.1016/j.jenvman.2024.120354
- Da Silva, P., Santos e Silva, C., Spyrides, M.C. and Andrade, L. (2019). Precipitation and air temperature extremes in the Amazon and northeast Brazil. *Int. J. Climatol.*, 39(2): 579-595. https://doi.org/10.1002/joc.5829
- De Souza, F., Duku, C. and Hein, L. (2023). Deforestation-induced changes in rainfall decrease soybean-maize yields in Brazil. *Ecol. Modell.*, 486: 110533. https://doi.org/10.1016/j.ecolmodel.2023.110533
- Espinoza, J.C., Ronchail, J., Guyot, J.L., Cochonneau, G., Naziano, F., Lavado, W., De Oliveira, E., Pombosa, R. and Vauchel, P. (2009). Spatio-temporal rainfall variability in the Amazon basin countries (Brazil, Peru, Bolivia, Colombia, and Ecuador). *Int. J. Climatol.*, 29(11): 1574-1594. https://doi.org/10.1002/joc.1791
- Espinoza, J.C., Ronchail, J., Lavado, W., Cochonneau, G., Oliveira, E., Pombosa, R., Vauchel, P. and Guyot, J. (2010). Spatiotemporal rainfall variability in the Amazon basin and its relationship to regional hydrological variability. A particular focus in the Andean region. *Rev. Peru. Geo-Atmosférica*, 2(2): 99-130.
- Fattah, M.A., Hasan, M.M., Dola, I.A., Morshed, S.R., Chakraborty, T., Kafy, A., Alsulamy, S., Khedher, K.M. and Shohan, A. (2024). Implications of rainfall variability on groundwater recharge and sustainable management in South Asian capitals: An in-depth analysis using Mann Kendall tests, continuous wavelet coherence, and innovative trend analysis. *Groundw. Sustain. Dev.*, 24: 101060. https://doi.org/10.1016/j. gsd.2023.101060
- Kendall, M.G. (1975). *Rank Correlation Methods*. (4th ed.). Griffin, pp. 160
- Lagneaux, E.G., Callo-Concha, D., Speelman, E.N. and Descheemaeker, K. (2024). Panarchy to explore land use: a historical case study from the Peruvian Amazon. *Sustain. Sci.*, 19:1187-1203. https://doi.org/10.1007/s11625-024-01502-9
- Lavado, W., Labat, D., Ronchail, J., Espinoza, J. and Guyot, J. (2012). Trends in rainfall and temperature in the Peruvian Amazon -Andes basin over the last 40 years (1965-2007). Hydrol. Process., 27(20): 2944-2957. https://doi.org/10.1002/hyp.9418
- Layza, R. and Gonzales, F. (2018). La deforestación y el cambio climatico en la provincia de San Martin periodo:1973-2014. *Cienc. y Tecnol.*, 14(2): 19-30.

- Lute, A.C. and Abatzoglou, J.T. (2021). Best practices for estimating near-surface air temperature lapse rates. *Int. J. Climatol.*, 41(S1): E110-E125. https://doi.org/10.1002/joc.6668
- Maillard, O., Vides-Almonacid, R., Salazar, Á. and Larrea-Alcazar, D.M. (2022). Effect of Deforestation on Land Surface Temperature in the Chiquitania Region, Bolivia. *Land*, 12(1): 2. https://doi.org/10.3390/land12010002
- Malhi, Y. and Wright, J. (2004). Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philos. Trans. R. Soc. London. Ser. B Biol. Sci.*, 359(1443): 311-329. https://doi.org/10.1098/rstb.2003.1433
- Marengo, J.A. and Camargo, C.C. (2008). Surface air temperature trends in Southern Brazil for 1960–2002. *Int. J. Climatol.*, 28(7): 893-904. https://doi.org/10.1002/joc.1584
- Mesia, J. (2015). Deforestación en el eje vial Iquitos y su relacion con la variabilidad climática local a traves de los años. Universidad Nacional de la Amazonia Peruana, pp. 83
- Pettitt, A.N. (1979). A Non-Parametric Approach to the Change-Point Problem. *Appl. Stat.*, 28(2): 126-135. https://doi.org/10.2307/2346729
- Pisconte, J.N., Vega, C.M., Sayers, C.J., Sevillano-Ríos, C.S., Pillaca, M., Quispe, E., Tejeda, V., Ascorra, C., Silman, M.R. and Fernandez, L.E. (2024). Elevated mercury exposure in bird communities inhabiting Artisanal and Small-Scale Gold Mining landscapes of the southeastern Peruvian Amazon. *Ecotoxicology*, 33:472-483. https://doi.org/10.1007/s10646-024-02740-4
- Restrepo-Coupe, N., O'Donnell, B., Longo, M., Alves, L.F., Campos, K.S., da Araujo, A.C., de Oliveira, R.C., Prohaska, N., da Silva, R., Tapajos, R., Wiedemann, K.T., Wofsy, S.C. and Saleska, S.R. (2023). Asymmetric response of Amazon forest water and energy fluxes to wet and dry hydrological extremes reveals onset of a local drought-induced tipping point. *Glob. Chang. Biol.*, 29(21): 6077-6092. https://doi.org/10.1111/gcb.16933
- Reygadas, Y., Spera, S.A. and Salisbury, D.S. (2023). Effects of deforestation and forest degradation on ecosystem service

- indicators across the Southwestern Amazon. *Ecol. Indic.*, 147: 109996. https://doi.org/10.1016/j.ecolind.2023.109996
- Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T., Salas, W., Zutta, B. R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M. and Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proc. Natl. Acad. Sci.*, 108(24): 9899-9904. https://doi.org/10.1073/pnas.1019576108
- Sen, P.K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. J. Am. Stat. Assoc., 63(324): 1379-1389. https://doi.org/10.1080/01621459.1968.10480934
- Sridhara, S. and Gopakkali, P. (2021). Trend and change point detection of seasonal rainfall for effective crop planning over southern transition zone of Karnataka, India. *J. Agrometeorol.*, 23(3): 316-323. https://doi.org/10.54386/jam.v23i3.36
- Silva, R., Lopes, A. and Santos, C. (2023). Deforestation and fires in the Brazilian Amazon from 2001 to 2020: Impacts on rainfall variability and land surface temperature. *J. Environ. Manage.*, 326: 116664. https://doi.org/10.1016/j.jenvman.2022.116664
- Smith, C., Baker, J.C.A. and Spracklen, D. V. (2023). Tropical deforestation causes large reductions in observed precipitation. *Nature*, 615(7951): 270-275. https://doi. org/10.1038/s41586-022-05690-1
- Swami, P. (2024). Trend analysis and change-point detection of monsoon rainfall in Uttarakhand and its impact on vegetation productivity. J. Agrometeorol., 26(1):103-108. https://doi. org/10.54386/jam.v26i1.2214
- Umeh, S.C. and Gil-Alana, L.A. (2024). Trends in temperatures in Sub-Saharan Africa. Evidence of global warming. *J. African Earth Sci.*, 213: 105228. https://doi.org/10.1016/j. jafrearsci.2024.105228
- Uwizewe, C., Jianping, L., Habumugisha, T. and Bello, A. (2024). Investigation of the Historical Trends and Variability of Rainfall Patterns during the March–May Season in Rwanda. Atmosphere, 15(5): 609. https://doi.org/10.3390/ atmos15050609