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ORIGINAL ARTICLE

Climatic variability and its association with dengue in the Coronel Portillo province, Peru

Variabilidad climática y su asociación con el dengue en la provincia Coronel Portillo, Perú

Variabilidade climática e sua associação com dengue na província de Coronel Portillo, Peru

Aldair Gama Gutierrez[I]*, Miguel Brayan Carrillo Freyre[II]

[I]Universidad Continental. Perú.
[II] Universidad Nacional de Ucayali. Perú.

***Corresponding author:** aldairgama0@gmail.com

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ABSTRACT

Introduction: numerous investigations have studied the link between climate variability and its effects on the epidemiology of dengue, highlighting the complex nature of this relationship due to the great adaptability of the Aedes vector. Studying climate variability as part of a comprehensive analysis of dengue epidemiology is essential to evaluate its impact on the recurring epidemics that occur. **Objective:** the present study sought to determine if there is an association between dengue cases reported from 2014 to 2023 in the province of Coronel Portillo, Peru, and climate variability, in the period January 2021 to December 2023. **Method:** the study was descriptive, reflective and analytical over time. The sources of information were obtained from the Regional Health Directorate of Ucayali and the National Meteorology and Hydrology Service of Peru. Statistical tests of cross-correlation between variables were carried out. **Results:** temperature showed a moderate positive correlation with reported dengue cases (0.594; P=0.042), as did precipitation (0.678; P=0.015).Regarding its correlation with the incidence of cases, it was 0.619 and P=0.032; and 0.675 and P=0.016, respectively. Humidity showed a very low correlation (0.111; P=0.732); Its correlation with the incidence of cases was 0.106 and P=0.744. The incidence of dengue cases presented a close connection with the reported dengue cases (0.998; P=0.00). **Conclusions:** the results reveal statistically significant correlations that suggest that the increase in dengue cases caused by the Aedes vector, in the province of Coronel Portillo, Peru, is associated with the climate variability that occurred from 2014 to 2023.

Keywords: climate change; climate variability; dengue; precipitation; temperature; Peru

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RESUMEN

Introducción: numerosas investigaciones han estudiado el nexo entre la variabilidad climática y sus efectos en la epidemiología del dengue, donde se destaca el carácter complejo de esta relación debido a la gran adaptabilidad del vector *Aedes*. Estudiar la variabilidad climática como parte de un análisis integral de la epidemiología del dengue es fundamental para evaluar su repercusión en las recurrentes epidemias acontecidas. **Objetivo:** el presente estudio buscó determinar si existe una asociación entre los casos de dengue reportados de 2014 a 2023en la provincia de Coronel Portillo, Perú y la variabilidad climática, en el periodo enero 2021 a diciembre de 2023. **Método**: el estudio fue descriptivo, reflexivo y analítico en el tiempo. Las fuentes de información fueron obtenidas de la Dirección Regional de Salud de Ucayali y del Servicio Nacional de Meteorología e Hidrología del Perú. Se realizaron pruebas estadísticas de correlación cruzada entre variables. **Resultados**: la temperatura mostró una correlación positiva moderada con los casos de dengue reportados (0,594; P=0,042), al igual que la precipitación (0,678; P=0,015). En cuanto a su correlación con la incidencia de casos fue de 0,619 y P=0,032; y 0,675 y P=0,016, respectivamente. La humedad mostró una correlación muy baja (0,111; P=0,732); su correlación con la incidencia de casos fue de 0,106 y P=0,744.La incidencia de los casos de dengue presentó una estrecha conexión con los casos de dengue reportados (0,998; P=0,00). **Conclusiones**: los resultados revelan correlaciones estadísticamente significativas que sugieren que el aumento en los casos de dengue producidos por el vector *Aedes*, en la provincia de Coronel Portillo, Perú, está asociado con la variabilidad climática ocurrida de 2014 a 2023.

Palabras clave: cambio climático; variabilidad climática; dengue; precipitación; temperatura; Perú

RESUMO

Introdução: inúmeras investigações estudaram a ligação entre a variabilidade climática e seus efeitos na epidemiologia da dengue, destacando a natureza complexa dessa relação devido à grande adaptabilidade do vetor Aedes. Estudar a variabilidade climática como parte de uma análise abrangente da epidemiologia da dengue é essencial para avaliar seu impacto nas epidemias recorrentes que ocorrem. **Objetivo:** o presente estudo buscou determinar se existe associação entre os casos de dengue notificados de 2014 a 2023 na província de Coronel Portillo, Peru, e a variabilidade climática, no período de janeiro de 2021 a dezembro de 2023. **Método:** o estudo foi descritivo, reflexivo e analítico ao longo do tempo. As fontes de informação foram obtidas na Direção Regional de Saúde de Ucayali e no Serviço Nacional de Meteorologia e Hidrologia do Peru. Foram realizados testes estatísticos de correlação cruzada entre variáveis. **Resultados:**a temperatura apresentou correlação positiva moderada com os casos notificados de dengue (0,594; P=0,042), assim como a precipitação (0,678; P=0,015).Quanto à sua correlação com a incidência de casos foi de 0,619 e P=0,032; e 0,675 e P=0,016, respectivamente. A umidade apresentou correlação muito baixa (0,111; P=0,732); Sua correlação com a incidência de casos foi de 0,106 e P=0,744. A incidência de casos de dengue apresentou estreita ligação com os casos notificados de dengue (0,998; P=0,00). **Conclusões:** os resultados revelam correlações estatisticamente significativas que sugerem que o aumento de casos de dengue causados pelo vetor Aedes, na província de Coronel Portillo, Peru, está associado à variabilidade climática ocorrida de 2014 a 2023.

Palavras-chave: mudanças climáticas; variabilidade climática; dengue; precipitação; temperatura; Peru

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Email: ric.gtm@infomed.sld.cu

INTRODUCTION

The relationship between climate variability and the incidence of vector-borne diseases, such as dengue, has been extensively studied in recent years. Several studies highlighted how fluctuations in climatic variables such as temperature, precipitation and humidity significantly influenced the transmission dynamics of dengue.[1,2,3,4] Islam, et al. concluded that climatic factors should be considered as one of the main determinants of the epidemiological complex, which encompasses vector ecology, pathogen biology, disease transmission, disease emergence and prevalence, as well as its control, prevention and cure.[5]

It was argued that approaching the epidemiology of dengue from a comprehensive understanding allowed a clearer mapping of the process of disease emergence and spread.[5] This was essential as risk assessment, prevention and control of this vector-borne disease were the only countermeasures of rigorous scope worldwide.[6]

Some authors noted that maximum dengue transmission was observed in months with high temperatures and rainfall, an observation consistent with patterns found in several endemic regions.[7] On the other hand, studies by Sanchez, et al. demonstrated a significant correlation between climatological variables and dengue incidence, underscoring the importance of considering these factors in planning control strategies.[2]

In the province of Coronel Portillo, Ucayali region, in Peru, the incidence of dengue showed an upward trend in recent years, coinciding with significant variations in local climatic conditions. Existing literature suggested a strong interdependence between climate and dengue incidence, which justified the need for specific studies to address this relationship in local contexts.[2,3,7]

For all of the above, it was decided to conduct this research with the objective of determining whether there is an association between reported dengue cases from 2014 to 2023 in the province of Coronel Portillo, Peru, and climate variability, in the period January 2021 to December 2023.

METHOD

The climatological variables considered for this study were temperature, relative humidity and precipitation on a monthly and annual time scale. The population considered for this study was that of the province of Coronel Portillo, Ucayali region in Peru, and the sample included the cases of dengue fever registered on a monthly basis during 9 years, which is the period of study of the research.

The data provided by meteorological variables were obtained from the National Meteorological and Hydrological Service of Peru (SENAMHI). A 9-year period was used as the basis for calculating the correlation coefficients with the use of dengue cases.

The climatological station from which data was obtained was Pucallpa. Annual averages were calculated from monthly data for trend analysis of the variables chosen (temperature, rainfall and humidity) in relation to the dengue cases reported by the Regional Health Directorate of Ucayali (DIRESA). Statistical graphs were made using Microsoft Excel.

All statistical analyses were performed using Microsoft Excel and SPSS statistical software. Several statistical techniques were applied to establish interactions within the climate-vector-disease nexus. To the best of our knowledge, the relationship has not been investigated in the area in a meaningful way, so the transmission dynamics with the climate factor are not well understood. As a focus of the study, the effect of climatic variables on the increase in dengue cases was analyzed. In addition, an attempt was also made to analyze the seasonal factors involved in the pattern of the reported epidemics.

To carry out the above steps, we proceeded to perform the analyses of meteorological data and dengue cases collected. First, normality tests were performed to determine if parametric linear regression models were applicable. This meant that for each value greater than or equal to 0.05, it was considered to be a normal variable. Once the normal nature of the variables was confirmed, the monthly data for mean temperature, relative humidity and total monthly precipitation for the period evaluated were condensed in summary form. This means, for example, that data were obtained for the mean temperature for each month in the period 2014-2023, and the same for the other variables involved. With the data summarized by month, the information of each meteorological variable was grouped in such a way that it could be compared and thus generates the possible correlations existing between them.

Then, an attempt was made to find relationships between the dengue cases reported on a summarized monthly basis and the climatological factors or variables for the period 2014-2023. The linear regression model assumed a fixed parametric form in the relationship between dengue cases and climatic factors. Thus, the analysis of dengue cases with the climatological variables considered was performed. The cross-correlation model was used to determine the Pearson correlation coefficients and subsequently interpret the results found.

RESULTS

Normality tests were carried out, the results of which showed that the variables considered had a value greater than 0.05. Temperature registered a value of 0.815; precipitation 0.252; humidity 0.997; dengue cases 0.278; and incidence 0.366. After completing the normality tests, correlation tests were performed between variables, seeking Pearson's correlation coefficient for each of the correlations identified.

Regarding climate variability during the years 2014 to 2023, the average mean temperature was 27.0°C, with an increase of 0.4°C towards 2023. Between 2014 and 2023, the variation was 0.4 °C. September and November were the warmest months, with 28.0 °C and 27.8 °C, respectively. While the least warm months were June and July, with 26.1 °C and 26.4 °C, respectively.

During the period under study, the average total annual precipitation was 1850.8 mm. The highest values were recorded in 2017, 2019 and 2020, with 2093.3 mm, 2096.7 mm and 2317.4 mmfor each of them. The months of November and March recorded the highest monthly average total precipitation, with 219.2 mm and 247.3 mm. The least rainy months were August and September, with values below the annual average. The climatic trend in the area, although showing variations in precipitation and temperature, remained within the acceptable range.

The average relative humidity value for the period 2014-2023 was 83.4 %. The months with the highest average relative humidity values were January and March, with 87.0 % and 85.7 %, respectively. The months with the lowest relative humidity values were August and September, with 80.4 % and 79.4 % respectively. During 2017, 2018 and 2019, a remarkable increase in relative humidity was observed, which then stabilized over the last years. The peak was reached in 2018, with 87.1 % annual average relative humidity. The relative humidity values coincided with the percentage range set for the tropical humid rainforest climate, according to the study location.

Dengue cases showed a clear rise over the last few years, taking into account the evaluated period of 2014-2023. Previously recorded epidemics also reported high peaks relative to the mean, although exact data prior to 15 years are unknown. The years with the highest dengue epidemics in the study area were 2020, 2021, 2022 and 2023, with a peak recorded during the COVID-19 pandemic, showing an upward trend. The September to March season recorded the highest number of dengue cases, with peaks in December and March. The dry season months coincided with the decrease in dengue cases reported annually. The results of the cross-correlation test are shown in Table 1.

Table 1 Test of correlations between climatological variables and epidemiological variables.

		Temperature	Precipitation	Humidity	Cases	Incidence
Temperature	Pearson correlation	1	0,264	-0,396	0,594*	0,619*
	Sig. (bilateral)	0	0,407	0,202	0,042	0,032
	N	12	12	12	12	12
Precipitation	Pearson correlation	0,264	1	0,623*	0,678*	0,675*
	Sig. (bilateral)	0,407	0	0,031	0,015	0,016
	N	12	12	12	12	12
Humidity	Pearson correlation	-0,396	0,623*	1	0,111	0,106
	Sig. (bilateral)	0,202	0,031	0	0,732	0,744
	N	12	12	12	12	12
Dengue cases	Pearson correlation	0,594*	0,678*	0,111	1	0,998**
	Sig. (bilateral)	0,042	0,015	0,732	0	0,000
	N	12	12	12	12	12
Incidence	Pearson correlation	0,619*	0,675*	0,106	0,998**	1
	Sig. (bilateral)	0,032	0,016	0,744	0,000	0
	N	12	12	12	12	12

*The correlation is significant at the 0.05 level (bilateral).
**Correlation is significant at the 0.01 level (bilateral).

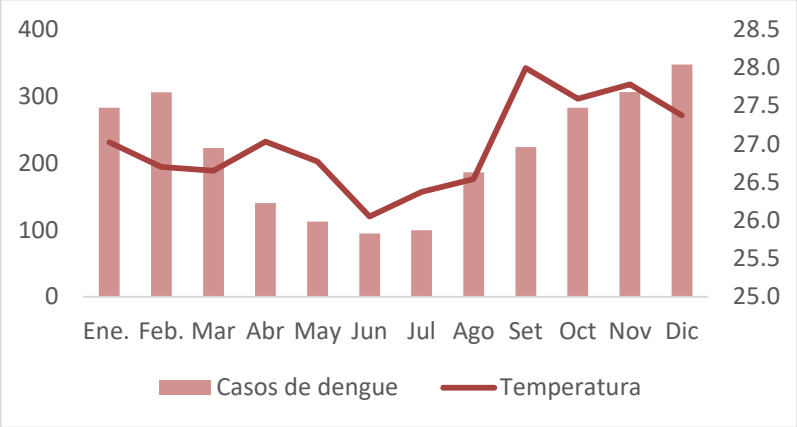
Temperature showed a moderate positive correlation with reported dengue cases. The Pearson correlation coefficient was 0.594 with a P=0.042. As for its correlation with the incidence of cases, the Pearson coefficient was 0.619 and a P=0.032; that is, P values less than 0.05, shown in the table as Sig. (Bilateral) or bilateral significance.

Precipitation showed a moderate positive correlation with reported dengue cases. Pearson's correlation coefficient was 0.678 with a P=0.015. As for its correlation with the incidence of cases, the Pearson's coefficient was 0.675 and a P=0.016; that is, P values less than 0.05.

Humidity showed a very low correlation with reported dengue cases. Pearson's correlation coefficient was 0.111 with a P=0.732. As for its correlation with the incidence of cases, the Pearson's coefficient was 0.106 and a P=0.744; that is, P values greater than 0.05.

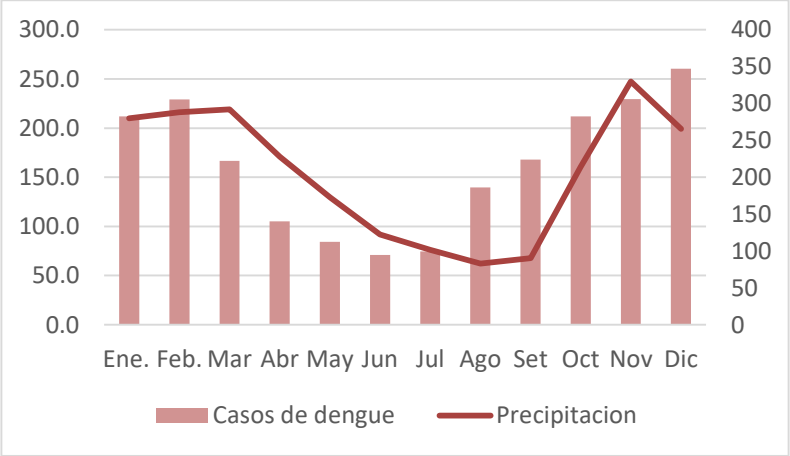
Dengue cases showed a very high correlation with reported dengue incidence. The Pearson correlation coefficient was 0.998 with a P=0.00.

In the province of Coronel Portillo, in the period evaluated, the mean temperature (Graph 1) increased steadily from the month of August; it reached its peak in September. From April to July, temperatures decreased, which was accompanied by a decrease in the number of dengue cases reported in those months. The Pearson correlation coefficient showed a significant correlation for the mean temperature/dengue cases relationship, as mentioned above.



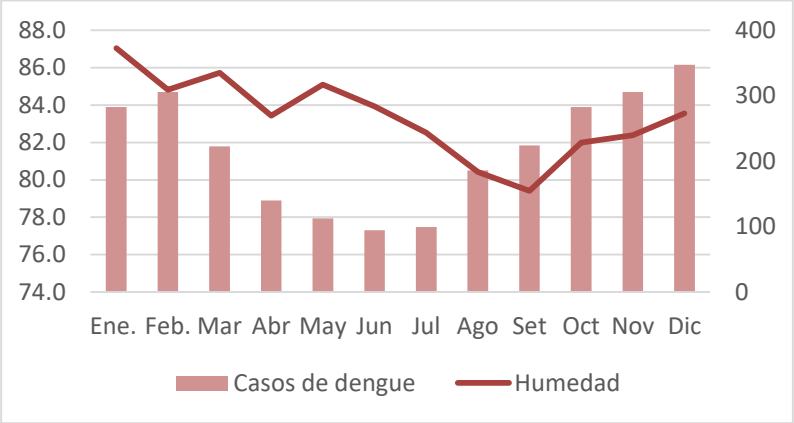
Graph 1 Dengue cases as a function of temperature 2014-2023.

In terms of precipitation, average total precipitation (Graph 2) increased steadily from October, reaching a peak in November, then stabilizing and registering a second peak in March. From March to August, precipitation decreased, which was accompanied by a decrease in the number of dengue cases reported in those months. However, it is important to mention that, in August, although rainfall continued to decrease gradually, dengue cases began to rise substantially. Pearson's correlation coefficient yielded a moderate to high correlation, considered significant in this study.



Graph 2 Dengue cases as a function of rainfall 2014-2023.

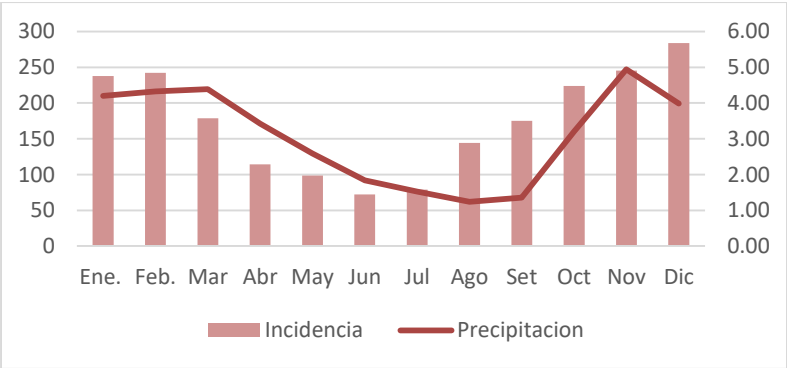
Humidity in the present study showed a dissonant behavior in relation to the other climatological variables. Humidity (Graph 3) was highest during the months of January and March. The graph shows that humidity was relatively higher during the first six months of the year, with a clear decrease in the period from July to September. Although the graph suggested a correlation with dengue cases, the correlation was weak, as evidenced by the results of the correlations performed.



Graph 3 Dengue cases as a function of humidity.

The incidence of dengue cases presented a close connection with reported dengue cases. Pearson's correlation coefficient was 0.998 with a P value of 0.00. As for humidity, the relationship found was weak, with a Pearson correlation coefficient of 0.106 and a P value=0.744.

The incidence of dengue cases presented a moderate correlation with precipitation and temperature, with Pearson coefficients of 0.675 and 0.619, respectively. The P values were 0.016 and 0.032. The incidence presented low values during the dry season months (Figure 4), with the highest values recorded in November and March. The graph showed that precipitation was relatively higher during November in the nine years evaluated, with a clear decrease in the period from June to September.



Graph 4 Incidence of dengue cases as a function of rainfall.

DISCUSSION

The variation of 0.4 °C during the period 2014-2019 expressed not only the natural variation in the climate of Coronel Portillo province, but also the complex relationship between climatological variables that influenced the transmission of dengue, and therefore, the increase in cases recorded over the years.

Climatological variables operated synergistically; precipitation and humidity influenced the increase in dengue transmission.[8] This was attributed to factors related to the mosquito's life cycle and the vector's relationship with the seasonality of the disease.

Temperature increases between 2014 and 2023, with variations of 0.4 °C, together with the constant rainfall recorded in the wet season, were identified as factors that increased the risk of dengue transmission. Peak dengue transmission was reported to coincide with months when high temperatures and precipitation were recorded, an observation that concurred with Xiao, et al. The WHO indicated that a temperature increase of 1 °C to 2 °C could result in several hundred million more dengue cases.[2,3]

This study recognized that the increase in dengue cases, which follows an upward trend, was not explained solely by climatological factors, but by a broad and complex relationship of factors, such as the territorial dispersion of the mosquito, environmental sanitation factors in urban areas, and failures in the control and storage of water in unsafe tanks.[9] However, the climatological variables provided satisfactory explanations of their medium- and long-term influence on the dengue epidemics recorded over the years.

The coincidence of the rising values of dengue cases with the curves of meteorological variables was explained by the conclusions of some authors, who indicated that climatic variability tends to have an effect on dengue cases recorded in an area where conditions suitable for the vector converge with optimal climatic conditions for its reproduction.[10]

Correlation analysis showed that temperature had a moderate positive variation with reported cases of dengue fever. The Pearson's evaluation coefficient was 0.594 with a P value of 0.042. These results were in agreement with studies conducted by Sanchez, et al. who evaluated the relationship between climatological variables and dengue infestation and incidence, obtaining significant correlations. Similarly, precipitation, by showing a moderate positive elevation, showed that as long as precipitation continues to rise, dengue cases could eventually skyrocket. Humidity, having shown a very low valuation, roughly coincided with the results found by Sanchez, et al. since the correlations were not statistically significant for this climatological variable.[2]

The dengue cases that showed a very high correlation with the reported incidence agreed in their interpretation with the results found by Islam, et al.[5] In 2023, the epidemic outbreak of dengue coincided with a historical rise in mean annual temperature, which had not been recorded in previous years; the average temperature in 2023 was 27.9 °C. This suggested an influence of the epidemic event with the temperature increase, according to the results and conclusions made by Marini, et al.[4]

Another point to consider was population density, an important factor for dengue transmission, although not the only one. In Callería, between 2020 and 2021, the trend of cases increased by 69.07%. According to DIRESA information, a large-scale epidemic similar to that of 2023 was recorded in 2012, attributed to the entry of vector serotype 2; since then this has been responsible for dengue epidemics. It was observed that serotype 2 is associated with increased mortality: 3 out of 4 deaths attributed to dengue are caused by transmission of that vector.

The incidence of dengue has increased during the last five years. Systematic review of the data provided answers to what causes can be attributed to this increase, according to the studies of Xiao, et al. and Marini, et al. it was concluded that a warm climate leads to increased viral replication, a higher load and, therefore, a higher risk of infection.[3,4]

Higher temperatures generated conditions for greater adaptability of the vector, which creates conditions conducive to reproduction, accelerated larval development and increased humidity in certain spaces, leading to a longer vector lifespan.[10] Therefore, by verifying a compensation, although not linear, it was placed as a contributing factor to the increase in cases.[11] Laboratory studies verified that Aedes adapted to survival at high temperatures, taking refuge in sewers and places with little solar influence. This led the mosquito to develop a better adaptive biological system in the face of climatic variability.[12]

It is concluded that an increase in dengue cases is associated with increased temperature, precipitation and, to a lesser extent, relative humidity during the wet season months in Coronel Portillo province. This, in turn, is reflected in the subsequent increase in the incidence of dengue in the same area.

It is recognized that only empirical attempts have been made to relate climatological variables to epidemiological variables of dengue disease, so this research opens doors to determine the causal relationships between climatic factors and the increase in dengue cases and incidence in the province. This study lays the groundwork for further research to address dengue prognosis in the Ucayali region and other areas of the Peruvian Amazon. This may prove vital as the climate continues to change and associated disease dynamics change as well.

The correlations made may help in the development of models that can lead to early warning systems for dengue epidemics. Based on the available information, we believe that studies should delve deeper into the associations between climate data and Aedes abundance during the wet season months. Future studies should expand knowledge on the dynamics of dengue in the region.

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Conflicts of interest:
The authors declare that there are no conflicts of interest.

Author contributions:
Aldair Gama Gutierrez: conceptualization, research, methodology, validation, visualization, project management, original draft-writing, drafting-revising and editing.
Miguel Brayan Carrillo Freyre: conceptualization, research, methodology, data curation, original draft-writing, drafting-revising and editing.

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