

IMPACT OF CLIMATE VARIABILITY IN THE OCCURRENCE OF LEISHMANIASIS IN NORTHEASTERN COLOMBIA

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Abstract. Previous studies have shown that variation in the distribution of vectors associated to the transmission of *Leishmania* species may be related to climatic changes. However, the potential implications of these ecological changes in human health need to be further defined in various endemic populations where leishmaniasis carries a substantial burden of disease such as in Northeastern Colombia. Herein, we report the impact of El Niño Southern Oscillation climatic fluctuations during 1985–2002 in the occurrence of cases of leishmaniasis in two northeastern provinces of Colombia. During this period, we identified that during El Niño, cases of leishmaniasis increased, whereas during La Niña phases, leishmaniasis cases decreased. This preliminary data show how climatic changes influence the occurrence of leishmaniasis in northeastern Colombia and contributes to the growing body of evidence that shows that the incidence of vector-borne diseases is associated with annual changes in weather conditions.

INTRODUCTION

Leishmania organisms are endemic in > 80 countries in almost every continent and are responsible for the visceral, cutaneous, and mucocutaneous forms of leishmaniasis. In the Americas, these diseases are transmitted by the bite of the infected female *Lutzomyia* sand flies.^{1,2} Various *Leishmania* species are prevalent in South America including members of the *Leishmania* subgenus (*Le. donovani* and *Le. mexicana* complexes) and *Viannia* subgenus (*Le. braziliensis* and *Le. guyanensis* complexes). Among the various ecological factors associated to the distribution of particular *Lutzomyia* species in the New World and *Phlebotomus* species in the Old World, climate seems to be a critical factor.^{3–5} Previous studies have indicated potential changes in the geographical distribution of certain vector sand flies associated to climate variability.^{6–9} Modeling studies in southwest Asia have been used to predict potential range expansion of *Phlebotomus papatasi* associated to global warming.^{6,7} In Italy, visceral leishmaniasis caused by *Leishmania infantum* is prevalent in the southern regions, where it is transmitted by *Phlebotomus perniciosus*.⁸ In this cycle of transmission, low temperature climate seems to be one of the main factors preventing its spread into northern Europe.⁴ However, other sand flies such as *Phlebotomus perfliewi*, suspected of transmitting cutaneous leishmaniasis, may be found in both temperate and tropical climates. While increases in temperature are likely to be conducive to the development of *Leishmania* organisms and sand fly vectors, the true impact of climate variability (including events such as El Niño Southern Oscillation [ENSO]) in the occurrence of leishmaniasis needs to be well delineated in various endemic areas for leishmaniasis.^{3,4}

ENSO is a climatic event that originates in the Pacific Ocean but has a wide range of consequences for weather worldwide. It is associated with flood and droughts in many areas of the world. In the case of South America, warm oce-

anic currents moving southward and that surrounds the coasts of Ecuador and Peru appear at the end of the summer season associated with increased rainfall in these areas and substantially influencing weather conditions in other regions in Latin America such as in Venezuela and Colombia. In northeastern Colombia, El Niño has been associated with droughts. It is important to note that climatic variability is referred to variations in the mean states of weather in each temporal and spatial scale, including those proceeding from events such as the ENSO, whereas climate change (or global climatic change) is defined as the persistence in those variations including its origin in natural physical processes but also by the influence of anthropogenic factors. Climate variability may have different impact in the transmission of leishmaniasis depending on the particular vectors and the various *Leishmania* species in different regions of the world.^{3–5,7} In general, sand flies are found in dry areas, then, when climate shift tends to dryer environmental conditions, vector populations could increase, and therefore, leishmaniasis transmission may be higher. Our study attempts to evaluate the impact of climate variability associated to ENSO events and its potential influence in the number of leishmaniasis cases in northeastern Colombia.

MATERIALS AND METHODS

We analyzed the impact of climatic variability associated with ENSO during 1985–2002 on the incidence of leishmaniasis cases (cutaneous and visceral forms) in Santander and North Santander, two locations in northeastern Colombia (Figure 1). These areas are endemic for cutaneous, mucocutaneous, and visceral leishmaniasis because these are Andean regions where ecological factors (climate, humidity, rainfall, and temperature among other meteorological elements) and social factors (agriculture—coffee and cocoa plantations) are highly conducive for *Lutzomyia* spp. development.^{1–3,10,11} The main vectors of leishmaniasis (caused by *Le. braziliensis*, *Le. panamensis*, *Le. mexicana*, and *Le. chagasi/infantum*) in this region are *Lutzomyia spinicrassa*, *Lu. serrana*, *Lu. shannoni*, *Lu. ovallesi*, *Lu. gomezi*, *Lu. trapidoi*, *Lu. yuilli*, and *Lu. hartmanni*.^{10,11}

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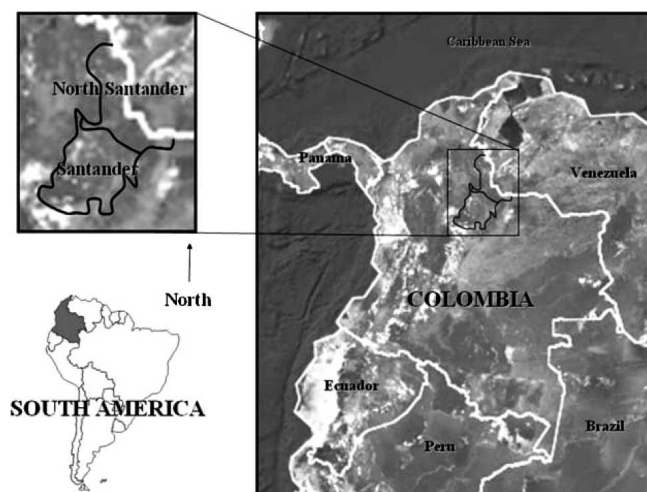


FIGURE 1. Map showing the relative position of Colombia and the study area in Northeastern departments of North Santander and Santander.

Climatic data were obtained from remote sensing systems from the available databases of the National Oceanographic and Atmospheric Administration (NOAA) for El Niño, Neutral, and La Niña periods, using the Southern Oscillation Index (SOI) and the Oscillation Niño Index (ONI) as variability indicators.¹² Classification of the climatic events was performed according to the NOAA criteria, which classify years corresponding to either El Niño or La Niña years. Epidemiologic data on cutaneous and visceral leishmaniasis was obtained from Colombia's Department of Health. In this analysis, all cases of leishmaniasis were considered (cutaneous, mucocutaneous, and visceral), although 97% of cases corresponded to tegumentary forms (96% cutaneous and 3% mucocutaneous) of leishmaniasis during the study period. While there is under-reporting of cases of leishmaniasis in these two areas, there is a well-established regional leishmaniasis control program that oversees the activities of both areas including case notification and registry, data analysis, and interpretation, as well as case management of patients. Quality control supervision of this epidemiologic data (collection, analysis, and interpretation) is carried out by the same supervising personnel in both areas. In addition, regional epidemiologic registries and operational activities within the program are supervised by the Ministry of Health (National Institutes of Health) of Colombia. Climatic events were assessed according to the NOAA with the SOI and ONI as global climatic variability indicators. We also analyzed the climatic and epidemiologic data using the Normalized Difference Vegetation Index (NDVI) to evaluate the influence of ecological factors between the two provinces. Negative values of NDVI could indicate vegetation decrease in the evaluated region (corresponding to dry environments), which could be associated with a significant landscape modification and consequently ecological conditions conducive for *Lutzomyia* spp. development and *Leishmania* spp. transmission. Conversely, positive values could indicate unmodified ecological areas with natural vegetation conditions with more stable or lower leishmaniasis transmission (corresponding to wet environments).

Climatic data and epidemiologic data were analyzed yearly

to identify variations in the number of leishmaniasis cases related to climate variability. Comparisons of annual proportional changes and climatic variations according to different seasons in terms of deviation from annual mean number of cases and in mean number of cases per season for each department was performed. In addition, linear regression models to assess the temporal leishmaniasis incidence variability, as well as the effects of SOI and ONI on leishmaniasis, were used. Statistical analyses were made with SPSS 10.0 and GraphPad Prism 4.0, with 95% confidence.

RESULTS

We identified substantial climatic variability during the study period. We noted important El Niño events during 1987, 1992–1994, 1997, and 2002, and significant La Niña events during 1988–1989, 1995–1996, and 1998–2001. During this period, a total of 18,765 clinical cases of leishmaniasis were registered in both locations: 11,947 in North Santander and 6,818 in Santander (Figure 2). The mean number of cases was 521 cases/yr (673 cases/yr for North Santander, Figure 2A; 378 cases/yr for Santander, Figure 2B).

We estimated the total number of cases per year and the average number of cases during El Niño and La Niña years. In this regard, we calculated the proportional deviation of cases, either above or under the median number of cases, which corresponded to El Niño and La Niña years with regard to the median of the entire study period for each Province (Figure 2C). We also compared the proportional change of leishmaniasis cases during El Niño years compared with La Niña years for each province (Figure 2D). We were therefore able to show that the average number of cases during El Niño years for both provinces was significantly higher for North Santander ($P = 0.0482$; Figure 2D).

During El Niño years an increase of up to 15.7% in disease incidence was observed in North Santander and 7.74% in Santander, whereas in La Niña, a decrease of 12.3% was evidenced in Santander and 6.8% in North Santander (Figure 2C). When mean annual leishmaniasis cases were compared between La Niña and El Niño years, we found significant differences for North Santander ($P = 0.0482$) but not for Santander ($P = 0.0525$; Figure 2D).

Linear regression models analysis combining both locations showed a higher value of SOI (tending to La Niña) and a decreased incidence of leishmaniasis, although not reaching statistical significance ($P > 0.05$). At higher values of ONI, an increased incidence of leishmaniasis was identified but did not reach statistical significance ($P > 0.05$). Nonsignificant differences were observed when the model was analyzed with each separated location.

We also were able to show that ecological factors prevailing in both areas were not significantly different between them as evidenced by the NDVI (Figure 3), but different in the ecological variability between seasons assessed by the NDVI during El Niño periods of 1987, 1992–1994, 1997, and 2002 (higher number of leishmaniasis cases) and during La Niña periods in 1988–1989, 1995–1996, and 1998–2001 (lower number of leishmaniasis cases), which corresponded with values < 0.06 during El Niño periods (dry seasons) and increased above 0.06 during La Niña periods (wet seasons; Figure 3).

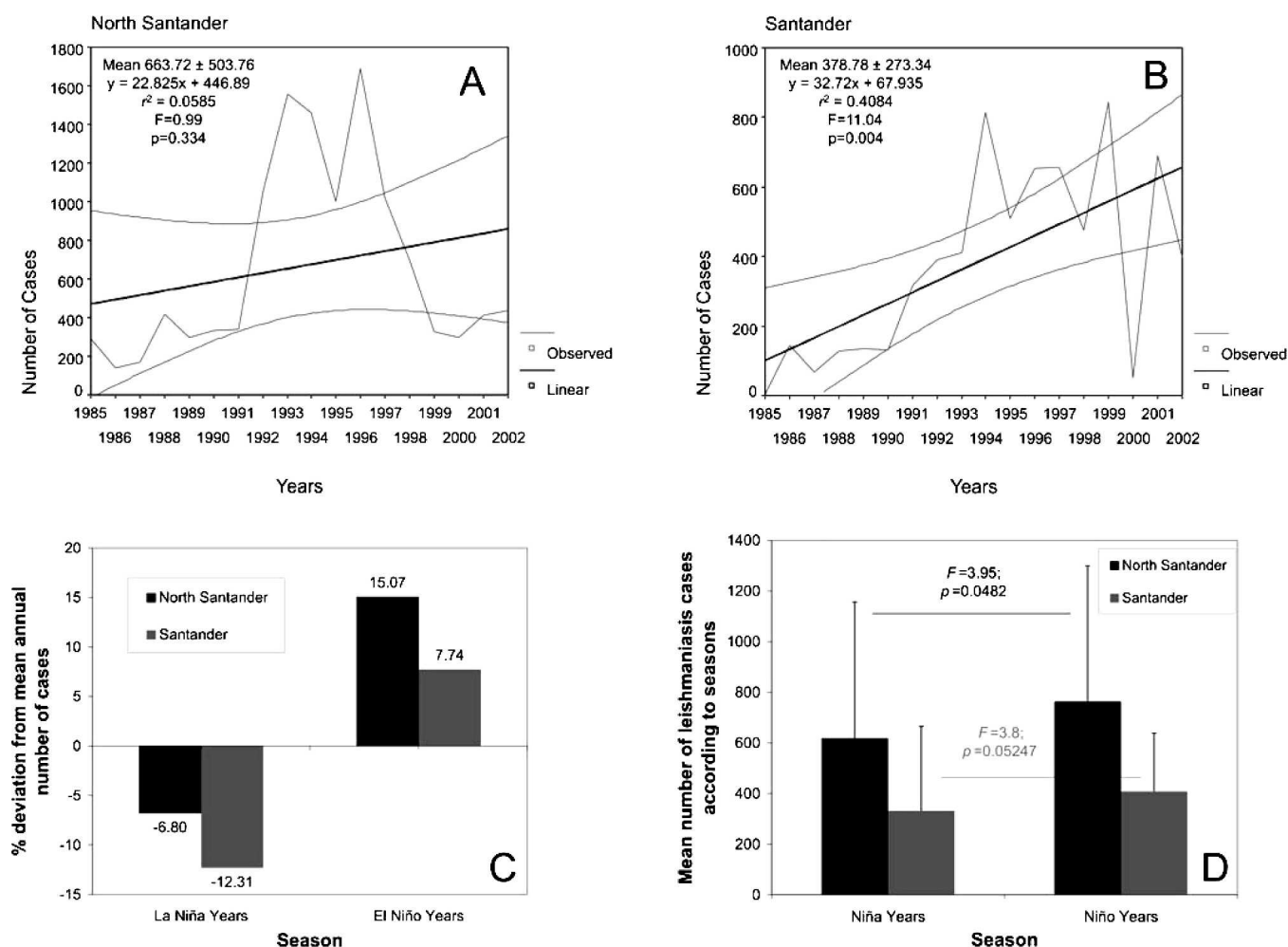


FIGURE 2. Leishmaniasis incidence in North Santander (A) and Santander (B) departments, northeastern Colombia; and possible impact of climatic variations according to different seasons in terms of deviation from annual mean number of cases (C) and in mean number of cases per season (D) for each department. El Niño years, 1987, 1992–1994, 1997, and 2002; La Niña years, 1988–1989, 1995–1996, and 1998–2001.

DISCUSSION

In this preliminary study, we showed that, in the absence of other biologic or social factors, climate variability may have a substantial impact in the epidemiology of leishmaniasis in northeastern Colombia. The world's climate seems to be changing at an unprecedented rate.^{4,5,13,14} Shifts in the distribution and behavior of insect vectors and bird species indicate that biologic systems are already adapting to ecological variations. It is well established that climate is an important determinant of the distribution of vectors and pathogens,^{4,5,13,14} such as those of malaria,^{15–17} dengue,¹⁸ and recently, leishmaniasis.^{6–9,19,20}

The statistical analysis of this study was based on the mean number of cases per year rather than on incidence rates in these populations. Therefore, because the analysis covered a long period of time and to avoid bias, we contemplated the rate of annual population growth in these populations. Both populations included in our study were considered to have a stable population growth of 1.0% to 2.5% annually, which does not significantly differ from other provinces in the country. Population growth data are not generated on a yearly basis because this information is obtained and estimated by

population censuses, which were carried out in 1985, 1993, 1999, and 2003 in Colombia. The population in Santander increased by 2% annually between 1985 and 1993 (1,511,392 individuals increased to 1,811,741 by 1993); from 1993 to 1999 showed a 1.09% annual population growth (1,938,910 individuals by 1999); and in 2003, there was a 1.23% annual growth (2,039,336 individuals by 2003). In the case of North Santander, the population growth by 1993 was 2.68% (population size increased from 913,491 in 1985 to 1,162,474 by 1993); a population growth of 1.95% between 1993 and 1999 (1,316,119 individuals by 1999); and a 2.07% annual population growth in 2003 (1,435,237 individuals by 2003). Based on these facts, we were unable to calculate exact incidence rates in these populations, which could only be estimated for the inter-census periods. However, our results show that the proportional variability associated to climatic changes at these locations was directly associated to a true increase in the number of cases of leishmaniasis independent of the stable population growth, particularly in Santander. In addition, we were not able to identify an increased notification rate directly attributable to increased awareness of the disease that could be responsible for the increased incidence of leishmaniasis cases at these locations.

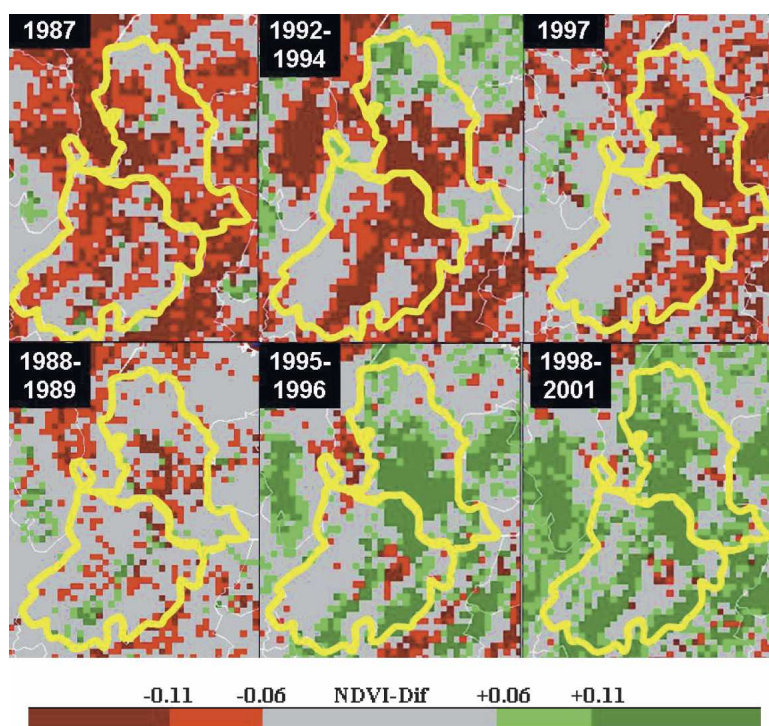


FIGURE 3. Variations in the normalized difference vegetation index (NDVI) (according NASA/GSFC) for North Santander and Santander during El Niño years (**top**) and La Niña years (**bottom**). Years 1987, 1992–1994, 1997, and 2002 corresponded to El Niño periods and years 1988–1989, 1995–1996, and 1998–2001 to La Niña periods, which was also evidenced by NDVI values < 0.06 during El Niño periods (dry seasons) and increased above 0.06 during La Niña periods (wet seasons). These numbers reflect a consistent pattern in the ecological factors between El Niño and La Niña periods, with more cases when NDVI values were < 0.06 and fewer cases when the values were > 0.06 . This figure appears in color at www.ajtmh.org.

Similar events are potentially taking place in other countries with similar ecological conditions and climatic variability, such as Brazil and Venezuela.^{9,20–22} These events need to be studied in different endemic areas because climatic changes may differently impact the occurrence of cases of leishmaniasis and other vector-borne infections. Although North Santander had a higher incidence of disease with more stable transmission ($P > 0.05$ at linear regression of incidence), cases in this location showed a significant deviation from the trend and mean number of cases in relation to El Niño years ($P = 0.04$; Figure 2). This is converse to what occurred in Santander, a location with decreased incidence, but more unstable transmission ($P = 0.004$ at linear regression of incidence) and a significant increase of cases over the study period, and where there were no significant differences in the incidence of leishmaniasis between El Niño or La Niña years. Our results therefore show geographical differences (or spatial heterogeneity) in the impact of climatic changes even within geographically close areas in northeastern Colombia.

We were also able to show that the ecological factors prevailing in both areas were not different as evidenced by the NDVI (Figure 3). Climate and ecological variability differences during El Niño periods (1987, 1992–1994, 1997, and 2002) and La Niña periods (1988–1989, 1995–1996, and 1998–2001) was evidenced by NDVI values < 0.06 during El Niño periods (dry seasons) and increased above 0.06 during La Niña periods (wet seasons). These numbers reflect a consistent pattern in the ecological factors between El Niño and La Niña periods, with more cases when NDVI values were < 0.06 and fewer cases when the values were > 0.06 . However, we

were unable to include rainfall and temperature records into our analysis given the fact that there are not appropriate historical records of these and other meteorological factors during the study period. In this regard, we have recently begun to prospectively collect this information that will be taken into consideration in future analyses that we will be carrying out in these same and other provinces in Colombia. Another important issue is the study of *Lutzomyia* spp. and the long-term impact of climatic variability on their populations, which appeared, given these results, that are environmentally favored when dry seasons are present, by facilitating reproduction and growth to adults of sand flies.

In summary, our study adds to the growing evidence linking human diseases to climate fluctuations and suggests that variations in the incidence of vector-borne diseases in Latin America and elsewhere are associated to annual changes in weather conditions. While we acknowledge that during the study period activities carried out by the leishmaniasis control program improved in terms of case management in both regions, the increased number of cases of leishmaniasis corresponds statistically and biologically, in a large proportion, with climate changes and far exceeds those that could be attributed to increased awareness and diagnosis of the disease in the two locations. Our results suggest that increased frequency of droughts, as expected under climate change scenarios for Colombia, is likely to increase the incidence of leishmaniasis in the region.

Given the substantial burden of disease associated to vector-borne diseases in developing tropical countries, it is of utmost relevance to incorporate climate changes into public

health thinking.^{5,9} Although our study may have some limitations such as a lack of incorporation of other meteorological factors into the analysis, we strongly believe that our findings are relevant from a public health perspective to better understand the ecoepidemiology of this and other tropical infections.^{5,9} However, further research is needed in this region and in other endemic areas to develop monitoring systems that will assist in predicting the impact of climate changes in the incidence of leishmaniasis and other vector-borne tropical diseases in endemic areas with various sand fly species and *Leishmania* species.^{4,5,7}

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