Analyzing the Effect of ENSO Related Weather Events on Waterborne and Vector Borne Disease Transmission in South America: A Literature Review

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Research Question:

How do ENSO weather events influence waterborne and vector borne infectious disease transmission in South America?

Abstract

The El Niño Southern Oscillation (ENSO) cycle has been shown to impact climate and ecology around the world. Its effect on infectious diseases transmission across South America has only been studied as isolated incidences or as general patterns on a limited geographic span. This literature review attempts to analyze vector borne and water borne diseases together and understand their resurgences and historical outbreaks in relation to the ENSO cycle. Ten peer reviewed articles that report on ENSO's effect on specific vector borne or waterborne diseases where chosen. The findings show that different diseases have different resurgence periods within the ENSO cycle. These resurgences are seen in either the warming El Niño or cooling La Niña effects on ambient temperature, water temperature and precipitation. ENSO events were also found to disproportionately cause disease resurgences based on tertiary factors like low socioeconomic status and population density. Future research should be used to develop effective disease prediction models, focusing on climate data and studying the interplay of hosts and human interaction and ENSO related weather events. Predictive disease modeling and effective surveillance systems should be further researched to prevent various infectious disease outbreaks in South America.

Table of Contents

Introduction:

In the past 10 years, climate change has been a highly studied topic in the scientific community. While there have been many hypothesized effects, its influence on human health in the form of communicable diseases has recently been a topic of discussion since the 2015 Zika outbreak in the United States. Climate change specifically affects vector borne (diseases transmitted to humans via animal hosts) and waterborne diseases because these disease outbreaks are tied to environmental and ecological changes (Castellanos, 2016). Waterborne and vector borne diseases usually see a spike in incidence rates when the host specie's lifecycle, habitat or breeding habits are altered (Moreno, 2006). South America, a continent that houses several infectious diseases at endemic levels, experiences a unique pseudo-cyclical pattern of climate change called El Niño Southern Oscillation (ENSO). El Niño is the convectional warming of the equatorial Pacific Ocean that happens every 2-7 years and affects climate patterns around the world. Its counterpart, La Niña is the counter-cooling of the equatorial Pacific Ocean (National Oceanic and Atmospheric Administration, 2020). Together, the warming, neutral, and cooling changes are called El Niño Southern Oscillation cycle. This cycle is measured under the Oceanic Niño Index (ONI). Lower values are associated with El Niño periods and higher values of ONI are associated with La Niña periods (National Oceanic and Atmospheric Administration, 2020).

These environmental changes have drastic effects on human health in South America, specifically to waterborne and vector borne illnesses (Castellanos, 2016; Moreno, 2006) . These ecological models are manipulated by the changing climate, whether it be the cooling or warming water convections. While ENSO may have influences on many different types of infectious diseases, this literature review will cover specifically water borne and vector borne diseases.

Surveillance systems are one key aspect in understanding and accounting for infectious diseases. Many countries in South America are considered developing countries and often do not have a uniform diseases surveillance system set up across all countries. It is important to note that many of these countries have unreported infections depending on the disease. Countries who earn a majority of their GDP off tourism, like Peru, often have better international communication about their local disease trends (Moreno, 2006). These systems are then used to determine prevention efforts. When discussing prevention efforts, a distinction need to be made when comparing water born illnesses with vector born illnesses. Vector borne disease prevention efforts have received funding depending on the type of disease. Mosquito born illnesses, or arboviruses, like dengue and malaria have gotten the most attention in prevention funds from the Pan American Health Organization (PAHO). PAHO is the governing body behind the implementation of the DDT eradication program in the 1950's and the current Integrated Management Strategy for the Prevention and Control of Dengue (IMS-Dengue) in 2003 (Castellanos, 2016). The *Plasmodium vivax* form of malaria is carried by *Anopheles (Nyssorhynchus) darlingi* mosquito and primarily found on the equatorial belt of South America in Peru and Brazil (Castellanos, 2016). Dengue, which is found in a similar region, is carried by *Aedes aegypti* and *Aedes albopictus (Castellanos, 2016).* Almost all South American countries have seen a drastic increase in the past 50 years. It should be noted that while these two predominant diseases are arboviruses, they are carried by different types of mosquito that have different breeding locations climate preferences. Other emerging arboviruses include Zika, West Nile virus, Chikungunya, and Venezuelan equine encephalitis (VEE) (Moreno, 2006). The occurrence of water borne diseases in South America is predominantly marked by increased rainfall and flooding that further affect impoverished communities (Hunter, 2003). Many water-related disasters in South America resulted in the resurgence of Cholera, regardless of geographic location (Hunter, 2003). Prevention has found its way in modern plumbing and appropriate disaster relief strategies.

Prediction models are one of the best tools available to predict disease rates. The combination of mathematical and GIS modeling is what some countries around the world have started doing when dealing with ENSO disease projections. Australia has recently implemented ENSO/dengue prediction model, to estimate Dengue incidence by zip code after the 2015 el Niño event in Queensland, Australia (Hu, Clements, Williams, & Tong, 2010). Similar large scale models like USAID's Famine Early Warning Systems Network (FEWS NET) risk assessment system, can take into account climate, economic, governance, and health data (Brown & Brickley, 2012). This technology paired with accurate surveillance systems could be applied to countries in South America in predicting both vector borne and waterborne illnesses. The downside to these models is the need for consistent data collection or surveillance systems that some countries in South America might not have.

The already increasing incidence rates of waterborne and vector borne diseases in conjunction with the pseudo-cyclical weather changes makes these disease rates a real threat to not only coastal South America but Central and North America as well. ENSO is great tool to study how overall climate change affects human health from an infectious disease prospective. The ENSO cycle can act as an estimated projection of the effect of global warming, and future models could be applied to other parts of the world. The known effects of ENSO weather events on the ecological cycle of disease transmission have been reported on for various diseases and countries in South America. ENSO events are most notably seen by 3 different weather effects:

Difference in atmospheric temperatures, increase or decrease in precipitation/ flooding and difference in ocean water temperature (National Oceanic and Atmospheric Administration, 2020). Each of these ENSO weather affects further influence infectious disease mechanisms or outcomes. A macro categorical view of each specific cause and effect has not been reported on.

This purpose of this literature is to explore vector borne and water borne infectious disease outbreaks that are caused by different effects of ENSO weather events. The synthesis of multiple infectious diseases and the ENSO related cause of their perspective increases will hopefully be an aid in understanding the interplay of each disease and give reason on why ENSO modeling for infectious disease prediction should be studied more.

Methods

Articles for the literature review were found in the Global Health database and the PubMed database. The Global Health database offers a variety of internationally published articles and also provides more information about determinants and risk factors for specific diseases that involve ENSO weather events. PubMed provided a more numerical accounting for disease morbidity in South America. Further information on search process can be found in *Figure 1: Process for Article Selection.*

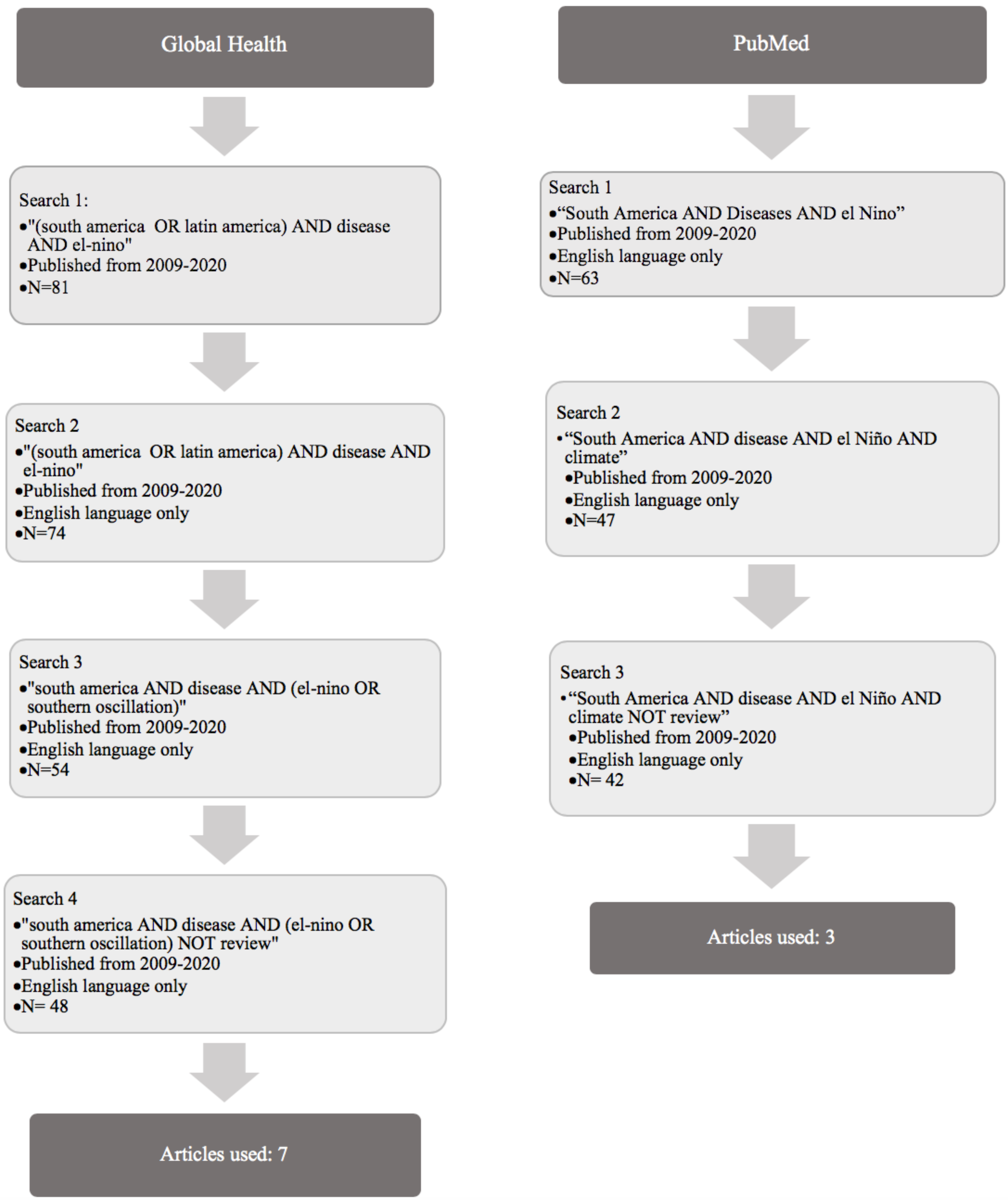
The Global Health Database initial search produced 81 articles with the phrase "(south america OR latin america) AND disease AND el-nino" published from 2009-2020. Many articles were not published in English so a second search with the “only English” selection marked was found to have 73 articles. The third search using the key words “south america AND disease AND (el-nino OR southern oscillation)" produced 54 articles. In the last search “NOT review" was added to eliminate all systematic and lit reviews and produced 48 articles. 7 out of the final 48 articles were used.

In the PubMed database, an initial search with the keywords "South America AND Diseases AND El Niño" produced 63 articles. A second search that added the phrase "AND climate" produced 47 articles. The last search added "NOT review" to eliminate all systematic and lit reviews and produced 42 articles. 3 out of the final 42 articles were chosen.

Inclusion and exclusion criteria

For both searches, only peer-reviewed articles published from the last 10 years were included to ensure the most relevant data. Searches were geographically limited to South America, any publications in Mexico or North America were excluded to narrow search results. Due to the fact that disease patterns and weather vary, and the same analysis could not be applied. Publications in other languages and without English translation were also excluded. Diseases were narrowed down to waterborne and vector borne diseases only, excluding STI and other chronic diseases. Only those with a published relation to ENSO weather events were used. All articles were chosen to study the effect of ENSO cycle on disease transmission.

Figure 1: Process for Article Selection



Results

After analysis of all 10 articles, each infectious disease was categorized as an arbovirus, mammal borne zoonotic virus or waterborne disease. Each disease resurgence was cross analyzed with ENSO cycle weather events. This resulted in 3 main ENSO related factors that influence disease resurgence: the warming El Niño cycle/low ONI values, the cooling La Niña cycle/ high ONI values, and other population-based tertiary affects. An overview of each article used can be found below in *Table 1: Detailed Summary of Articles Reviewed*.

El Niño/ Low ONI values

El Niño is known for its warm ambient air and sea temperatures as well as increased rainfall, further causing flooding and decreased ocean salinity (National Oceanic and Atmospheric Administration, 2020). The increased rainfall was found to affect many waterborne diseases including *Vibrio parahaemolyticus*, *Vibrio vulnificus* and cholera. Shellfish host infection of *V. parahaem*olyticus and *V. vulnificus* increased during El Niño weather events in coastal South America due to decreased water salinity and more favorable water temperatures (Raszl, Froelich, Vieira, Blackwood, & Noble, 2016). Cholera cases were found to have increased during the end of El Niño cycles, indicating that gradual flooding and sanitation degradation were intermediate causes of the resurgence (Ramírez, Lee, & Grady, 2018).

Malaria, zika and dengue arbovirus resurgences were all associated with El Niño events, presumed that both ambient temperature and rainfall are more favorable for mosquito breeding. Studies done in both Venezuela and Colombia found increased dengue incidence rates strongly associated with lower ONI values (El Niño), and lower dengue incidence with higher ONI values (Herrera-Martinez & Rodríguez-Morales, 2010; Quintero-Herrera et al., 2015). Both malaria strains, *Plasmodium vivax* and *Plasmodium falciparum*, were also found to increase during El Niño in both Venezuela and Peru (Grillet, El-Souki, Laguna, & León, 2014; Ramírez et al., 2018). Specifically, the study done in Venezuela concluded that malaria transmission was suppressed by heavy rainfall and increased in months after El Niño events (Grillet et al., 2014). This study also characterized the increased incidence rates to 3-6 year cycles and 2 year cycles depending on strain type and geographic location, lending insight to the complexity of the impacts rainfall has geographically (Grillet et al., 2014). Zika transmission was also expected to increase due to mosquito host breeding preferences of El Niño weather events according to a 2017 modeling study (Caminade et al., 2017). To add to the vector borne disease resurgences, an increased number of hantavirus rodent species found after ENSO event indicates greater chance for rodent to human transmission (Maroli, Vadell, Padula, & Gómez Villafañe, 2018).

La Niña/ High ONI values

La Niña is noted for having particularly cold weather, including cooler ambient air and sea temperatures as well as increased rainfall, depending on the location in South America (National Oceanic and Atmospheric Administration, 2020). A 2019 study found infection rates of leptospirosis, a waterborne bacterial infection, increase by 25% during La Niña and decrease by 17% during El Niño in Colombia (Arias-Monsalve & Builes-Jaramillo, 2019). The vector borne diseases leishmaniasis, a parasitic disease with a sand fly vector, is shown to have increased incidence rates during the La Niña cooling phase in northern South America and Panama (Chaves, Calzada, Valderrama, & Saldaña, 2014). The study of leishmaniasis also found a lag time between host population increases and actual human infection, indicating that human behavior in regard to weather is another facet to study. Both leptospirosis and leishmaniasis found their La Niña associated resurgence in northern South America, indicating that the increased rainfall attributed to La Niña in specifically northern South America could be the reason for the disease resurgence.

Tertiary social and spatial determinants

Population density and socioeconomic status are all considered tertiary effects of ENSO related disease increases. A multi-disease mapping article during El Niño year analyzed reported diseases on multiple levels, including socioeconomic to study the occurrence and risk factors for what areas of Peru where affected. Findings showed that low SES status put villages more at risk for multiple disease outbreaks, specifically malaria and cholera during ENSO weather events (Ramírez et al., 2018). The impact ENSO events have on disease resurgence regarding SES and population density can be seen in Panamanian minority group “Comarca Madungandi”, who experienced increased malaria infections from January 1980 to April 2013 (Hurtado, Cáceres, Chaves, & Calzada, 2014). This article also indicated that the regime change in 2001 that defunded malaria on control efforts also had a negative effect on malaria transmission during El Niño years. In both cases, SES and population density are both factors that increased morbidity of such diseases specifically during el Niño years.

Table 1: Detailed Summary of Articles Reviewed

	Author	Year	Article Title and Journal	Purpose of Article	Sample info	Type of research	Findings	Limitations
1	Arias-Monsalve, C. S.; Builes-Jaramillo, A.	2019	Impact of el Niño-Southern Oscillation on human leptospirosis in Colombia at different spatial scales. ***Journal of Infection in Developing Countries***	Measures the bacterial/ human leptospirosis infection rates and ENSO water temp changes in Colombia between 2007-2015	National, departmental and municipal level data for leptospirosis cases *mandatory reporting*	Cross-sectional retrospective	Lack of rainfall in ENSO cycle causes an increase in Lep. Cases - 25% rise in the monthly number of cases during La Niña - 17% decrease during El Niño	El Niño weather may cause people to bathe in rivers and ponds increasing the risk of exposure (important confounder)
2	Caminade, C. Turner, J. Metelmann, S. Hesson, J. C. Blagrove, M. S. Solomon, T. Morse, A. P. Baylis, M.	2017	Global Risk Model for Vector-Borne Transmission of Zika Virus Reveals the Role of El Niño 2015 ***Proceedings of the National Academy of Sciences of the United States of America***	Identify changes in R0 internationally vs. in South America for Zika	Global historical climate data of ENSO cycle used to make 2015 South America El Niño model (Model runs on both Ae. Aegypti and by Ae. Albopictus vectors)	Ecological Model/ R0 calculation	2015 El Niño climate phenomenon was conducive for Zika transmission over South America. *Zika entered SA in 2013 *Transmitted by Ae. albopictus, but because Ae. albopictus extends beyond the range of Ae. aegypti into more temperate regions)	Zika is still relatively new to South America, historical data is not reliable

3	Chaves, L. F.; Calzada, J. E.; Valderrama, A.; Saldaña, A.	2014	Cutaneous leishmaniasis and sand fly fluctuations are associated with El Niño in Panamá. ***PLoS Neglected Tropical Diseases***	Study how ENSO events effect Cutaneous leishmaniasis transmission via sand fly host in Panama	Data collected from all the health facilities from 2000-2011 by Panama´s Ministry of Health. Passive case detection. 640 night-trap sampling.	Cross-sectional	CL epidemics occur during the cold phase of El Niño (ENSO) or La Niña compared to regular cycle -3-month lag time	Only looked at sand-fly vector population, not actual CL human transmission
4	Grillet, M. E.; El-Souki, M.; Laguna, F.; León, J. R.	2012	The periodicity of Plasmodium vivax and Plasmodium falciparum in Venezuela. ***Acta Tropica***	Malaria over the last 20 years in Venezuela. Studies both Plasmodium vivax and Plasmodium falciparum	State- and municipality-level cases of *P. vivax* and *P. falciparum* were obtained from the Malaria Control Program database, Venezuelan Ministry of Health.	Retrospective Ecological	Rainfall mediated the effect of ENSO on malaria locally. Cycles of malaria were intensified in months following the El Niño events - Malaria is suppressed in the period with most rainfall, especially in the Amazonas region	Not all cases of malaria were reported 20 years ago
5	Herrera-Martinez, A. D.; Rodríguez-Morales, A. J.	2010	Potential influence of climate variability on dengue incidence registered in a western pediatric Hospital of Venezuela. ***Tropical Biomedicine***	To calculate Dengue incidence rate changes over 7 years at pediatric hospital.	Pediatric hospital in western Venezuela. (2001-2008) 7,523 cases of dengue	Retrospective Ecological	Found correlations between El Niño and La Niña. higher dengue incidence with lower values of Oceanic Niño Index (ONI) (El Niño periods) and lower dengue incidence with higher values of ONI (La Niña periods)	Only accounts for children's cases

6	Hurtado, L. A.; Cáceres, L.; Chaves, L. F.; Calzada, J. E.	2104	When climate change couples social neglect: malaria dynamics in Panamá. ***Emerging Microbes and Infections***	To determine why Malaria cases are still high in minority populations.	Monthly malaria cases for Comarca Madungandí, Panama from January 1980 to April 2013. Obtained from the East Panamá Region Vector Control Department of Panamá's Ministry of Health	Case study	Malaria disproportionately affects minority Amerindian populations during El Niño years -The poor are affected more by malaria, rural areas vs. nonrural -Historical context, shows how prevention efforts need reach all populations and geographic areas	Small sample size
7	Maroli, M.; Vadell, M. V.; Padula, P.; Gómez Villafañe, I. E.	2018	Rodent abundance and hantavirus infection in protected area, east-central Argentina. ***Global Health Database***	The purpose of this long-term study was to identify factors affecting hantavirus infection and reservoir population	-6 habitats in the Otamendi Natural Reserve in Buenos Aires Argentina -650 animals 752 times for 15,833 trap-nights -3 known hantavirus rodent host species	Cross Sectional	Increased number of hantavirus rodents found after ENSO event indicates greater chance for rodent to human transmission	Only indication on why El Niño even affected was breeding pattern. Further research needed on breeding.
8	Quintero-Herrera, Et al	2015	Potential Impact of Climatic Variability on the Epidemiology of Dengue in Risaralda, Colombia, 2010-2011 ***Emerging Infectious Diseases***	Impact of ENSO weather events on Dengue transmission in Colombia	Risaralda, the most populated city, had 946,626 residents in year 2014 and is composed of 14 municipalities.	Ecological study	Found both surface temp and rainfall pattern were both indicators of increased dengue transmission during El Niño events ($p < 0.01$)	Does not include information about previous El Niño years

9	Ramírez, I. J.; Lee Jieun; Grady, S. C.	2018	Mapping multi-disease risk during el Niño: an ecosyndemic approach. ***International Journal of Environmental Research and Public Health***	To explore mapping multi-disease risk during El Niño-Southern Oscillation (ENSO) and hydro-meteorological extremes in northern Peru *7 climate-sensitive diseases	District data from Piura, Peru January to March 1998. Looked for: -acute diarrheal diseases -Cholera -acute -respiratory infections - P. falciparum and P. vivax -Conjunctivitis	Retrospective Ecological	Shows the interplay between 2+ diseases in one place -Locations that we most often dually infected had the highest rates of poverty	-Sample area small and not representative of other South America countries -Poverty plays a role in exposure types
10	Raszl, S. M. Froelich, B. A. Vieira, C. R. Blackwood, A. D. Noble, R. T.	2016	Vibrio Parahaemolyticus and Vibrio Vulnificus in South America: Water, Seafood and Human Infections ***Journal of Applied Microbiology***	To determine whether shellfish host infection of Vibrio parahaemolyticus and Vibrio vulnificus transmitted to humans increases in ENSO events.	South American case reports for both illnesses from 1997-2015	Ecological study of case reports	Salinity and temperature Atlantic coast varied between 14.4°C and 35°C	-Only western coast of South America coincides with el Niño events -Many unreported cases

Discussion

While it had been clearly stated that ENSO cyclical weather patterns do have an effect on infectious disease rates, a broader understanding of the temporality of these disease resurgences is needed. Vector borne and waterborne diseases persist in South America and studying how weather phenomena affects their lifecycles as a whole will lend to better disease prediction modeling in the future.

When determining ENSO's effects on infectious disease transmission, it's important to understand the wide variety of host variation and breeding preference that are impacted. The ENSO cycle manipulates key features of these precise and delicate life cycles. Water temperature, atmosphere temperature and precipitation are three factors that go into ensuring pathogens can continue to breed and pass along their genetic material. In the articles reviewed, this impact is seen even within same host type. When looking at malaria and dengue diseases, both use mosquito vectors, however each disease is affected slightly different by ENSO cycle.

This literature review established 3 key aspects of the ENSO weather cycle that impact host/disease behavior. The first being that El Niño weather events have the greatest effect on diseases in South America out of the ENSO cycle. Arboviruses studied like dengue, malaria, and zika all had increased incidence rates, however some peaked at different points during the ENSO cycle. For example, both malaria and dengue cases increases during El Niño but malaria cases peak at the end of the cycle while dengue case rates remain relatively consistent (Quintero-Herrera et al., 2015; Ramírez et al., 2018). Since Zika is a relatively new disease to the South American content, not much data has been collected, however future research might be able to model after dengue incidence patterns because both diseases are carried by the same *Ades* mosquito species (Caminade et al., 2017). Waterborne diseases outbreaks were mainly dependent on rainfall and/or ocean salinity, often occurring later in the El Niño season. This might indicate how waterborne diseases prevention methods are used in the future.

The second key aspect of the review found that La Niña did have an effect on disease transmission, but mainly in northern South America. Both studies that reported *leptospirosis* and *leishmaniasis* incidence rate increases attributed the resurgence to increased rainfall patterns specifically related to La Niña (Arias-Monsalve & Builes-Jaramillo, 2019; Chaves et al., 2014) While a majority of research efforts have looked at the prominent effects of El Niño on transmission, it is important to understand that both the warming and cooling can have an effect on diseases and their host.

The last finding concluded that tertiary social and spatial determinants like poverty and population density further amplify ENSO related increases in disease incidence. This could be a result of the combination of animal host behavior as well as human host behavior. Poverty or SES status might mean lack of access to prevention resources and also might coincide with living in rural vs. urban settings. Areas with a high poverty rate were specifically found to have a higher disease burden, maybe caused by lack of El Niño preparation, aid, or medical care (Ramírez et al., 2018). Malaria host *Anopheles* mosquito often breed in standing water in less populous environments, which might explain the increase in malaria specifically in rural areas (Hurtado et al., 2014). These two factors combined with favorable breeding conditions due to an El Niño event result in disproportionate disease burden.

The findings of this study coincide with the majority of previously published literature. The main exception would be the specific analysis of La Niña events. This is because a majority of studies are specifically interested in El Niño effects and not La Niña events since it is a better indicator of future global warming weather patterns as a whole. The goals of studying ENSO effects on diseases can be seen on two levels. The first being immediate effects on South America and how to improve disease prevention and eradication programs. The second being on a global level, to study how future climate change effects diseases. While findings might be more highly regarded when studying ENSO for a climate change perspective, the public health prospective could help shape more effective prevention programs for a specific population or location. In most papers published about this subject, historical context of disease eradication programs is not thoroughly represented numerically when only looking at ENSO effects on said diseases. This is important to account for when expanding the results to central America and north America, as these locations have had more aggressive disease prevention efforts in place. For example, the PANO malaria eradication project was far more successful in Mexico and Central America than South America, in the 1960's (Castellanos, 2016). Only one paper out of 10 analyzed took previous disease eradication programs and external factors into account (Hurtado et al., 2014). Applying the findings and trends of South America to any other part of the world needs to also take into account outlying factors, such as previous prevention programs, SES and population density accounted for. Whether research is done for a public health understanding or climate change understanding, both require precise and accurate data that can be used for disease modeling based on ONI values.

Limitations

There could have been new research conducted or research awaiting publication that was therefore not available for the analysis during the time at which this review was written. This review is primarily limited by the handful of waterborne and vector borne diseases in which it covers. There are many other diseases in South America, and those analyzed in this review merely touch the surface of the vast interplay between hosts. Geography span should also be accounted for as not all countries from South America are represented in this review. Specifically, when searching databases, there were very few published articles from Brazil, and none met final inclusion criteria. Not including data on the largest country in South America does not give an accurate representation of South American disease patterns on the eastern coast of South America. Additionally, this review is limited to only reviewing articles in English versus articles written in Spanish or Portuguese. Since the proposed area of study Spanish or Portuguese is predominantly spoken and written, it would increase the quantity and quality of articles to review. Lastly, this review only covered 10 articles and is limited to the past 10 years.

Further Research and Implications

To further understand some of the less common or neglected tropical diseases, more ecological research should be done. Improved surveillance systems and the ability to retrieve accurate data uniformly from all countries would lend to a better understanding. South American public health research intuitions should focus on preventions strategies for disease epidemics by understanding ENSO cycles and promoting public health campaigns to alert the public in accordance to weather patterns. In addition, surveillance systems should be a top priority for health officials in South American countries. Influence of PANHO in particular to set up a single surveillance database for diseases other than dengue would also lend to better data. Better data leads to predictive disease modeling.

Conclusion

The effects of ENSO on infectious disease rates are still not well understood on an ecological level. The complex ecological relationships between hosts and weather can easily be affected by climate change. To reduce the burden of both waterborne and vector borne diseases in South America, more research is needed to understand how ENSO related disease outbreaks can be prevented. ENSO weather event research also sheds light on how future climate change may affect the spread of waterborne and vector borne infectious diseases.

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