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El Niño Southern Oscillation

El Niño Southern Oscillation and the prevalence of infectious diseases: review

El Fenómeno del Niño y la prevalencia de enfermedades infecciosas: revisión

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Abstract

Climate changes caused by the El Niño oscillation southern (ENSO) significantly influence human diseases, because they are related to anomalies in precipitation or periods of drought. The aims of this paper are: to evaluate the anomalies of the average sea surface temperature, to calculate the average sea surface temperature of the Niño and Niño 1+2 regions, to contextualize infectious pathologies according to their classification: viral, bacterial, parasitic and caused by fungi in the geographical areas or countries of the Region where they have been studied in the historical context (1982-1983; 1997-1998 and 2016-2017) periods of the ENSO considered strong. A bibliographic, descriptive, documentary, retrospective and cross-sectional review was carried out during the months of October 2023 to March 2024. Sea Surface Temperatures (SST) are higher than average, observed throughout the equatorial Pacific Ocean, with anomalies being greater in the central and central-eastern Pacific. For ENSO 2023-2024, in the Niño 4 region the last calculated values of the Niño index remained at a temperature of +1.4 $^{\circ}C$, in the Niño 3,4 region it was +1.9, in the Niño -3 region it was +2.0 $^{\circ}C$ while in the Niño-1+2 regions it weakened to +1.0 $^{\circ}C$. The highest incidence and prevalence of ENSO infection (1997-1998) in Ecuador stands out, accounting for an increase in 13 infectious pathologies. Attention must be paid and the links between the environment and the risk of infection must be better understood.

Keywords: ENSO, temperature, climate, changes, infectious pathologies.

Resumen

Los cambios climáticos causados por el Niño oscilación sur (ENOS) influyen significativamente en las enfermedades humanas, debido a que está relacionado con anomalías en las precipitaciones o períodos de sequía. El presente trabajo estableció como objetivos específicos: evaluar las anomalías del promedio de la temperatura de la superficie del mar, calcular el promedio de la temperatura de la superficie del mar de las regiones del Niño y Niño 1+2, contextualizar las patologías infecciosas según su clasificación: virales, bacterianas, parasitarias y causadas por hongos en las áreas geográficas o países de la Región donde han sido más estudiadas en el contexto histórico (1982-1983; 1997-1998 y 2016-2017) períodos de ENOS considerados fuertes. Se realizó una revisión bibliográfica, descriptiva, documental, retrospectiva y de corte transversal durante los meses de octubre 2023 a marzo de 2024. Las temperaturas de la Superficie del Mar (TSM) son superiores al promedio observándose por todo el Océano Pacifico ecuatorial, siendo mayores las anomalías en el Pacifico central y centro-este. Para ENOS 2023-2024, en la región Niño 4 los últimos valores calculados del índice Niño se mantuvieron a una temperatura de +1,4 $^{\circ}C$, en la región Niño 3,4 fue de +1.9, en la región Niño -3 fue de +2,0 $^{\circ}C$ mientras que en la región Niño -1+2 se debilitó a +1,0 $^{\circ}C$. Destaca la mayor prevalencia de infección de ENOS (1997-1998) en Ecuador, contabilizando un incremento en 13 patologías infecciosas. Se debe prestar atención y comprender mejor los vínculos que existen entre el medio ambiente y los riesgos de infección.

Palabras clave: ENSO, temperatura, clima, cambios, patologías infecciosas.

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1 Introduction

The El Niño/Southern Oscillation (ENSO) is a climatic phenomenon that modulates climate variability on both global and national scales on an interannual timescale (NOAA, 2024). ENSO causes abnormal warming of the Pacific Ocean waters near the coasts of Peru and Ecuador, impacting the Indian Ocean, equatorial southern Africa, South America, and marginally Europe (Huarcaya Castilla et al., 2004; Rúa-Uribe et al., 2013). ENSO also refers to disruptions in the normal circulation of the ocean and atmosphere (Huarcaya Castilla et al., 2004; Rúa-Uribe et al., 2013; NOAA, 2024). Occurring at intervals of 2 to 7 years, ENSO influences oceanic components associated with changes in Sea Surface Temperature (SST) in the tropical Pacific Ocean and also affects atmospheric components (Kovats, 2000; NOAA, 2024; Latif et al., 2015). It is related to variations in atmospheric pressure between the western and eastern tropical Pacific Ocean, disturbing global climate through atmospheric teleconnections (Huarcaya Castilla et al., 2004; Rúa-Uribe et al., 2013; NOAA, 2024; Carlowicz and Schollaert, 2017; Kovats, 2000; Li et al., 2021).

El Niño/La Niña events are parts of the global climate cycle. El Niño is characterized by the warming of equatorial Pacific waters, while La Niña occurs during the cooling phase. During El Niño, the western coasts and extreme south of South America experience intense rainfall, causing higher water levels, while the northern subcontinent and much of Central America and the Caribbean suffer from reduced precipitation, leading to droughts and a high risk of wildfires. Conversely, La Niña sees the opposite pattern (Marinho et al., 2022; Fleck, 2022; Huarcaya Castilla et al., 2004; Fuller et al., 2009; Moraes et al., 2019; Kovats, 2000; Fan et al., 2017).

Due to the vast size of the Pacific Ocean basin, which spans one-third of the planet, changes in temperature, wind, and humidity are transmitted globally. Therefore, ENSO is an ocean-atmosphere interaction phenomenon related to climate variability (Del Carpio, 2023). Ocean condition variations cause changes in weather patterns and fisheries along the western coasts of the Americas (NOAA, 2024). In South America, ENSO impacts result in flooding along the west coast of Ecuador, Peru, and Colombia and droughts in the Amazon and northeast of the continent. Additionally, dry areas in countries like Peru, Chile, Mexico, and the southwestern United States often experience flooding from rains and snow, with arid deserts blooming. Meanwhile, the wetter regions of the Brazilian Amazon and northeastern United States frequently suffer from prolonged droughts (Carlowicz and Schollaert, 2017; Huarcaya Castilla et al., 2004; NOAA, 2024; Cai et al., 2020; Del Carpio, 2023; Lam et al., 2019; Da Silva et al., 2020; Yglesias-González et al., 2023).

The climatic changes caused by ENSO significantly influence human diseases. ENSO is associated with precipitation anomalies in many cities worldwide, where excessive rainfall or drought periods lead to an increase in infections with high epidemic risks, such as vector-borne diseases, dermal diseases, diarrheal illnesses, and lower respiratory tract infections (Arbo et al., 2022; Flahault et al., 2016).

These conditions tend to increase infection risks, exacerbated by poor water storage practices, lack of access to clean water, insufficient sanitation facilities, open defecation, unsafe drinking water supply, and poor solid waste management, leading to increased pests and vectors (Loayza-Alarico and De La Cruz-Vargas, 2021; Anderson, 2010; Lam et al., 2019; Da Silva et al., 2020; Kovats, 2000; Molleda and Velásquez, 2022; Arbo et al., 2022; Woyessa et al., 2023).

Malaria is one of the most studied diseases in this context. A study conducted in Piura, Peru, between 1996 and 1997 found that the highest incidence of cases occurred in May, following the April rains (Huarcaya Castilla et al., 2004; Cai et al., 2020). The research revealed that breeding sites and vector development increased, with transmission favored by ambient temperature even at unusual altitudes. This observation was corroborated in western Kenya, where malaria outbreaks were noted at altitudes above 2000 meters if temperatures exceeded 18 °C and precipitation surpassed 15 $mm^3/month$ (Huarcaya Castilla et al., 2004). Such climatic changes influence the living conditions, longevity, and dynamics of adult Anopheles mosquitoes, impacting disease transmission (Huarcaya Castilla et al., 2004).

Similarly, a team of researchers found a strong relationship between ENSO-driven weather conditions in the Pacific and dengue epidemics in Sri Lanka. Their findings indicated that the dengue risk increased with weekly rainfall exceeding 50 mm. The strongest correlation between precipitation and dengue occurred six to ten weeks after weekly rainfall exceeded 300 mm, under extremely humid conditions and high flooding probability. They noted that temperatures rising to 30 °C or higher consistently increased the dengue risk, with a delay of four weeks post-event (Liyanage et al., 2016; Fuller et al., 2009).

ENSO's global climatic variability influences social and economic components, but its impact on human health is not well understood (Anttila-Hughes et al., 2021). During ENSO periods in coastal regions near the Pacific Ocean, anomalies in temperature and precipitation often result in landslides, floods, wildfires, droughts, and other natural disasters, affecting community health. It is crucial to identify the prevalence of diseases triggered by these extreme weather events to develop prevention plans to mitigate epidemics or vector-borne infectious, viral, bacterial, parasitic, or fungal diseases.

This literature review was conducted to evaluate sea surface temperature anomalies, calculate the average sea surface temperature in Niño regions, analyze ENSO temperature increases in Niño 1+2 Region (Pacific region affecting Ecuador), based on data from the National Oceanic and Atmospheric Administration (NOAA). The review also examined air temperature and monthly precipitation to contextualize and classify infectious diseases into viral (Dengue, Zika, Chikungunya, Rift Valley Fever, Influenza, Enterovirus), bacterial (Leptospirosis, Shigellosis, Cholera, Salmonellosis, Plague), parasitic (Cryptosporidiosis, Schistosomiasis, Leishmaniasis), and fungal (Mycosis, Coccidioidomycosis, Pityriasis) categories that have affected populations in regions studied during strong ENSO events in 1982-1983, 1997-1998, and 2016-2017.

2 Materials and Methods

A bibliographic, descriptive, documentary, retrospective, and cross-sectional investigation was conducted between October 2023 and March 2024. The study was structured through a literature search in the *Pubmed* database (https://pubmed.ncbi.nlm.nih.gov/). Additionally, articles published by the WHO (https://www.paho.org/es, https://www.cdc.gov/), and the National Oceanic and Atmospheric Administration (https://www.noaa.gov/education/resource-collections/weather-atmosphere/el-nino) were considered.

The following search equations were used as filters in the search engine bar, using DeCS/MeSH descriptors: "Infectious Diseases", "Vector-Borne Diseases", "Dengue", "Zika", "Chikungunya", "Rift Valley Fever", "Respiratory Diseases", "Diarrhea", "Cholera", "Salmonellosis", "Shigellosis", "Plague", "Hantavirus", "Cryptosporidiosis", "Leishmaniasis", "Mycosis", "Coccidioidomycosis", and "Pityriasis" for the classification of viral, bacterial, parasitic, and fungal diseases. To associate infectious diseases with climatic factors, the following terms were searched: "ENSO", "ENSO and diseases", all combined with the Boolean operators AND, OR, NOT, and NOR. Figure 1 shows the algorithm used to select articles and the search and selection strategy for carrying out the bibliographic review.

Inclusion criteria were as follows: articles published from 2000 to 2023, focusing on infectious diseases and their relationship with ENSO climatic variations during the strong periods of 1982-1983, 1997-1998, and 2016-2017. Original peer-reviewed articles in indexed journals, comparative studies, evaluation, and meta-analyses published in English, Spanish, and Portuguese were included. These articles provided quantitative associations with epidemiological data between viral, bacterial, parasitic, and fungal diseases in the population and ENSO. Excluded from the research were guidelines, letters to the editor, editorials, theses, and dissertations. Articles in languages other than Spanish, English, or Portuguese, and those not published between 2000 and 2023 were also excluded.

2.1 Data collection

The literature search was verified twice to ensure consistent results. For vector-borne viral diseases, the following articles were found: 429 for dengue, 139 for Zika, 182 for Chikungunya, 156 for Rift Valley Fever, 91 for Leptospirosis, 235 for Influenza, 19 for Enterovirus, 69 for Salmonellosis, 33 for Plague, 3 for Shigellosis, 38 for Cryptosporidiosis, 111 for

Leishmaniasis, 2 for Mycosis, and 3 for Coccidioidomycosis. These articles were evaluated to apply exclusion and inclusion criteria, then organized in an Excel sheet by infectious disease, ENSO year, and geographic area to select those best suited to the study objectives.

Subsequently, the selection of articles was based on the geographic area affected by ENSO, the years in which data were recorded (1982-1983, 1997-1998, 2016-2017), and the type of infectious disease presented (viral, bacterial, parasitic, and fungal).

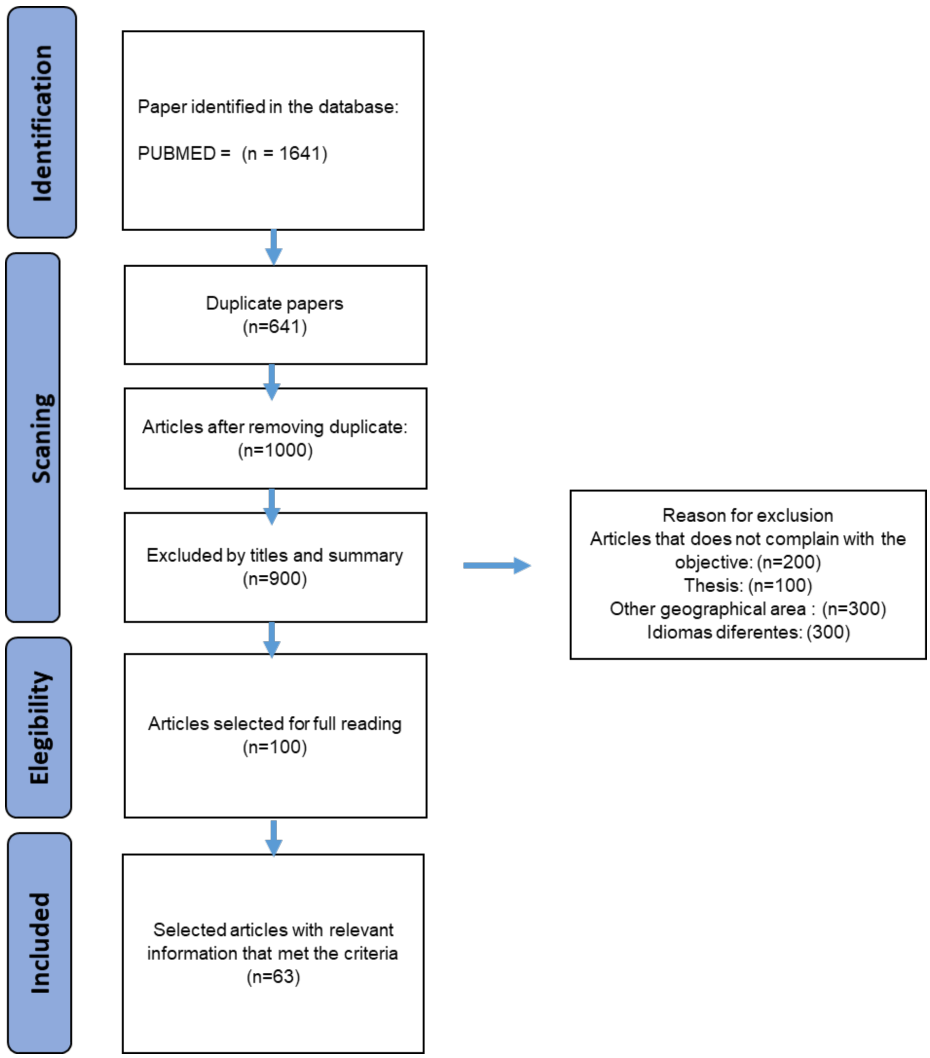

Figure 1. Algorithm Used for Article Selection. Search strategy and selection of scientific articles for conducting the literature review.

3 Results and Discussion

Figure 2 shows that Sea Surface Temperatures (SST) are above average across the equatorial Pacific Ocean, with the greatest anomalies observed in the central and east-central Pacific. According to the National Oceanic and Atmospheric Administration (NOAA), NOAA's Climate Prediction Center, and the National Weather Service, there is a 73% probability that the 2023-2024 ENSO will be considered "Neutral"for the months of April to June 2024. In December 2023, positive subsurface temperature anomalies in the Pacific Ocean decreased, indicating a strengthening and eastward expansion of subsurface temperatures that will be below average in the Western Pacific (NOAA, 2024). Therefore, ENSO in some Niño regions may not cause as much damage as the strong El Niño events.

Due to the vast expanse of the Pacific Ocean, ENSO has been divided into Niño regions or areas. According to the ENSO regions in the Pacific Ocean (Figure 3), for the 2023-2024 El Niño event, the latest calculated Niño index values were as follows: in the Niño 4 region, the temperature remained at +1.4 °C; in the Niño 3.4 region, it was +1.9 °C; in the Niño 3 region, it was +2.0 °C; while in the Niño 1+2 region, it weakened to +1.0 °C (NOAA, 2024).

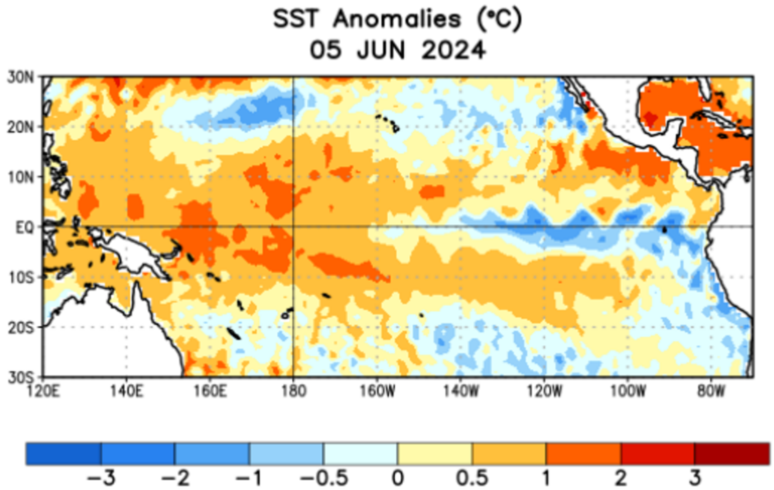

Figure 2. Anomalies of the Average Sea Surface Temperature (SST) °C for the Week Centered on January 3, 2024. The anomalies are calculated relative to the weekly averages of the 1991-2000 base period. Source: NOAA, (2024).

In the Niño 4 and Niño 3.4 regions, SST increased from April, progressively rising from June and peaking in December. The Niño 3 region showed an increase in SST starting in March, with the highest temperatures observed during September, October, November, and December 2023. In the Niño 1+2 region, which affects countries such as Ecuador and Peru, temperatures increased from February, remained high until June, decreased, and then rose again from July through December, starting to decline in December.

Figure 4 shows the evolution of ENSO from 1957-58, 1965-66, 1982-1983, 1991-1992, 1997-1998, 2009-2010, 2015-2016, up to November 2023, with respect to temperature (the years in red are considered strong El Niño events). This graph evidences how the 1982-83 ENSO period evidenced temperatures rise by 4 °C from July to January, and during the 1997-1998 El Niño event, temperatures also reached 4 °C from March to September (NOAA, 2024). The Niño 1+2 region is the area of the Pacific Ocean used to observe the climatic variations caused by ENSO in Peru and Ecuador. This graph shows sea surface temperature (SST) anomalies in the Niño 1 and Niño 2 regions with coordinates 0-10° South, 90° West, 80° West. The values were calculated from the monthly ERSST V5 by NOAA/CPC (NOAA, 2024).

The El Niño events of 1982-1983 and 1997-1998 are considered the most significant of the 20th century due to the severe catastrophes they caused, especially in South America, which prompted governments and researchers to conduct more studies to understand the nature of ENSO and, thus, predict it to mitigate the impact of climatic disasters caused by this event (Kovats, 2000). The black line represents the 2023-2024 ENSO, where the SST begins to decrease from January 2024. For this reason, the El Niño phenomenon of this period is considered neutral or moderate because temperatures did not exceed 2.5 °C (NOAA, 2024).

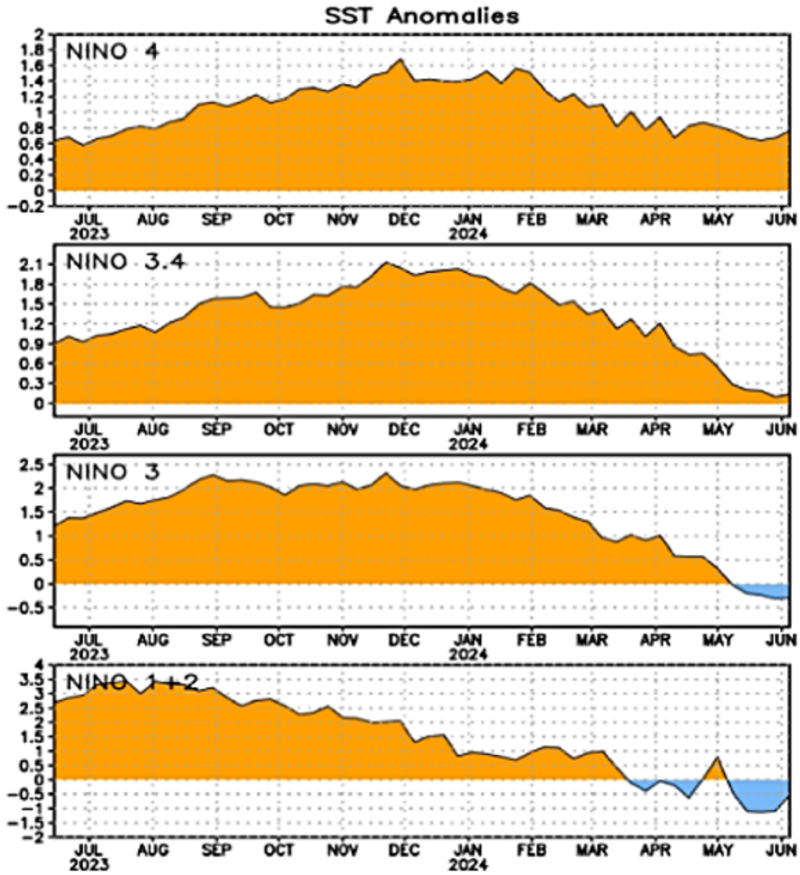

Figure 3. Time Series of the Average Sea Surface Temperature Anomalies. Anomalies in °C for the Niño regions: Niño-1+2 (0°S, 90°W-80°W), Niño-3 (5°S, 150°W-90°W), Niño-3.4 (5°N-5°S, 170°W-120°W), and Niño-4 (5°N-5°S, 150°W-160°E). The anomalies are calculated relative to the weekly averages of the 1991-2000 base period. Source: NOAA ,(2024).

Table 1 shows the prevalence of infectious diseases during the strongest El Niño events of the 20th century (1982-1983, 1994-1995, 1997-1998) reported for South American countries such as Ecuador, Peru, Bolivia, Venezuela, and Colombia. The highest incidence and prevalence of ENSO (1997-1998) was observed in Ecuador, with an increase in 13 infectious diseases. Brazil ranks second, showing an increase in encephalitis cases (Rio, West Nile Virus, and Rocio) during the 1994-1995 El Niño. Thirdly, malaria cases rose significantly in Bolivia, Colombia, Ecuador, Peru, and Venezuela during the 1982-1983 event. Similarly, dengue cases in Ecuador, Peru, and Brazil increased significantly in 2016-2017.

In Table 2, out of a total of 1641 articles found in the consulted database, 63 articles that met the review's objectives and inclusion/exclusion criteria were selected. These articles are classified according to the type of disease: viral, bacterial, parasitic, and fungal. From the 1641 articles, 429 were related to Dengue, of which 10 were selected as they met the study's objectives. For Zika, 6 out of 139 articles were selected. For Rift Valley Fever, 3 out of 156 articles were selected. For Enterovirus, 3 out of 19 articles were selected. For infectious Gastroenteritis, 1 out of 42 articles was selected. For Influenza, 6 out of 235 articles were selected.

Regarding bacterial diseases, 7 out of 91 articles on Leptospirosis were selected. For Cholera, 4 out of 273 articles were selected. For Shigellosis, 2 out of 3 articles were selected. For Plague, 2 out of 33 articles were selected. In the literature search on parasitic diseases, 2 out of 111 articles on Leishmaniasis were selected. For Cryptosporidium, 2 out of 38 articles were selected. For Cyclospora, 1 out of 6 articles was selected. For fungal diseases, 1 out of 2 articles on Mycosis was selected, and 2 out of 3 articles on Coccidioidomycosis were selected. Additionally, 5 articles that dealt with infectious diseases in general and the influence of ENSO were selected, as they were considered relevant and met the study's objectives.

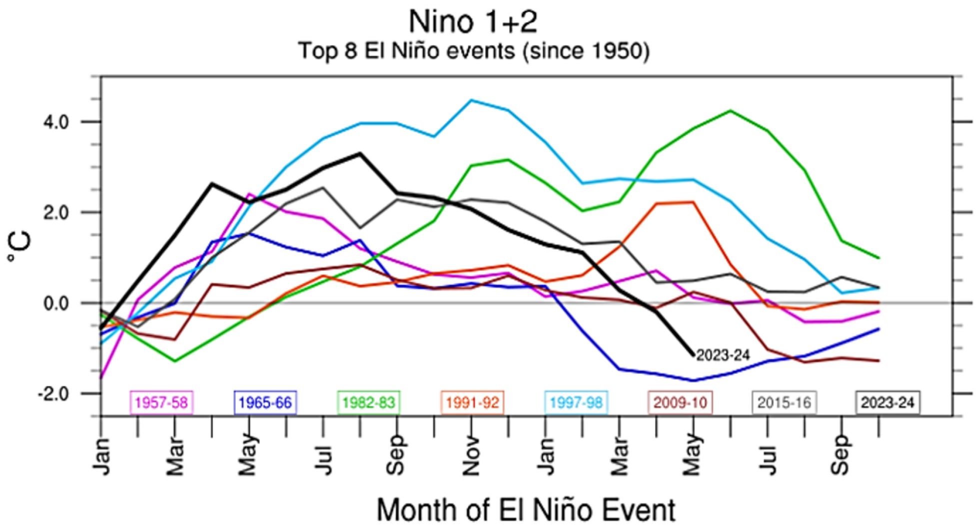

Figure 4. Sea Surface Temperature (SST) Relationship from the 1950 El Niño Event to the 2023 El Niño Event. Source: NOAA, (2024).

Fisman et al. (2016) conducted a study related to ENSO and infectious diseases in the United States. They identified groups of diseases that can cause epidemiological changes due to climate change: vector-borne diseases, viral diseases causing conditions such as pneumonia and influenza, enteric diseases, bacterial, zoonotic, parasitic, and fungal diseases. Evaluations of historical ENSO events did not show the presence of fungal diseases, suggesting that daily morbidity records from health centers and hospitals should be reviewed to determine their occurrence.

The study also found an increase in the prevalence of tick-borne diseases due to elevated temperatures and precipitation, which favored the presence of ticks and other rodents that serve as reservoirs for diseases such as Babesiosis, Lyme disease, and Rickettsiosis, among others (Fisman et al., 2016). It has been documented that the transmission rate of microorganisms is higher with shorter tick life cycles due to high temperatures, suggesting that ENSO could increase the number of tick-borne disease cases beyond usual expectations (Rodríguez Arranz and Oteo Revuelta, 2016).

Due to the irregular periodicity of ENSO with strong temperature and precipitation variability patterns affecting the risk of infectious diseases, some studies demonstrated a significant impact on vector-borne diseases in the Western United States, without showing morbidity in other regions. In this regard, vectors move according to water availability needed for breeding site survival, which could be influenced by either the lack of water resources or the implementation of permanent vector control strategies in that region.

3.1 El Niño Southern Oscillation and viral diseases

Li et al. (2016) evaluated an emerging viral infection caused by *Coxsackievirus 16* and *Enterovirus*, affecting children and infants in China. The clinical presentation includes fever, vesicles, and ulcers in the hands, feet, and mouth. While clinical symptoms can be mild, severe neurological symptoms such as meningitis, encephalitis and polio-like paralysis can occur, as well as pulmonary edema. The study analyzed how ENSO and climatic variations affect this disease. They determined that high Southern Oscillation Index values were associated with an increased incidence of the disease. The study suggested that meteorological factors predict the occurrence of this infection in China.

Table 1. Infectious Diseases Associated with the El Niño Phenomenon in Latin America (2000-2019).

Disease	Country or region	Year of the El Niño Phenomenon	Reference
Malaria	Ecuador, Peru, Bolivia, Venezuela and Colombia	1982-1983	Kovats (2000)
Paludism	Ecuador, Peru, Bolivia, Colombia	1982-1983	Huarcaya et al. (2004)
West Nile Encephalitis Ross River Fever Rocio Encephalitis	Brasil	1994-1995	Huarcaya et al. (2004)
Cholera Conjunctivitis Diarrhea Sexually transmitted diseases Yellow Fever, Chagas Hepatitis Leishmaniasis Leptospirosis Marsh fever Paludism Plague Chickenpox	Ecuador	1997-1998	OPS (2000)
Dengue	Peru Ecuador Brasil	1997-1998 2010-2011 2015-2016	Huarcaya et al. (2004) Stewart et al. (2013); Lipi et al. (2018) Anyamba (2019)

On the other hand, Oluwole (2017) conducted a study demonstrating that ENSO dynamics drove the incidence of seasonal influenza from 2009 to 2019, a period during which severe seasonal flu epidemics coincided with ENSO dynamics. The authors concluded that the combination of all influenza pandemics over the past 140 years, with chaotic low-transitivity regimes, shows that ENSO dynamics contribute to driving influenza pandemics. Therefore, all models forecasting this event should complement influenza virus surveillance from now on.

Similarly, studies conducted in Japan by Zaraket et al. (2008) found that the highest peak of influenza was related to the warm ENSO period (Xiao et al., 2022; Tang et al., 2022). The warm phase of El Niño, where sea surface temperatures are abnormally high, occurs during the first seven months of the year, followed by a drop in temperature below normal. This could lead to large-scale environmental changes that alter the trend of flu viruses to redistribute and transmit to the human host.

Latinne and Morand (2022) expressed that climate variability and anomalies are factors driving the emergence of infectious diseases. They highlighted the association between climatic factors like ENSO, land surface temperature anomalies, and the emergence and transmission of viral diseases from bats to humans and livestock in Asia, the Pacific region, and the Arabian Peninsula. The authors found that ENSO and its climatic anomalies can create opportunities for spreading bat-transmitted rabies viruses to humans and animals. Their results suggest that most of these viral diseases transmitted by bats were likely caused by ENSO climatic anomalies, as 9 out of 12 bat-transmitted viruses emerged in the Asia-Pacific region and the Arabian Peninsula after an El Niño event.

Additionally, the recent emergence of the SARS-CoV-2 virus responsible for COVID-19 in China in 2019 occurred after an ENSO event that impacted China. According to these authors, the bat-transmitted viruses include the Coronaviridae, Paramyxoviridae, Reoviridae, Rhabdoviridae, Nipah virus, and Hendra virus. Regarding SARS-CoV-2, which appeared in Wuhan, China, it was likely transmitted from bats to humans through an intermediate host believed to be a pangolin. The transmission chain, involving caging wild animals in food markets, subsequent slaughter, and contamination in sales areas, presents high risks for pathogen transmission to both buyers and market workers, leading to the rapid spread of the virus to the broader population (Silva-Jaimes, 2020).

Furthermore, it affected the biodiversity of invasive species, causing loss of local flora and fauna due to aggressive exploitation without adequate biological controls, invading ecosystems unsustainably results in infectious outbreaks by disrupting the balance between predators and prey. However, it is believed that the bat moved unusually from its habitat due to climate change.

Climate change has accelerated the anthropogenic emission of greenhouse gases, increasing zoonosis risks. Additionally, global warming increases the number of infectious disease vectors, such as mosquitoes and ticks. Global warming directly influences pathogens with a higher thermal range than their hosts, including humans, where the balance between the invasive pathogen and the host's immune system shifts in favor of the pathogen. Another important aspect is the migration patterns of wildlife, which could favor the emergence of new diseases through interactions between different animals. Moreover, increased global trade fosters interactions between wild fauna and domestic animals, leading to greater global exposure of humans to pathogenic microorganisms, promoting the transmission of zoonotic diseases, COVID-19 being an example (Valladares, 2020).

3.2 Southern Oscillation El Niño and vector-borne viral diseases

According to Anyamba et al. (2019), the investigation into patterns of interannual climate variability related to ENSO indicates that it results in climatic and environmental anomalies in specific regions worldwide, leading to outbreaks or increases in a wide variety of diseases, notably Dengue, Chikungunya, Zika, Hantavirus, Rift Valley Fever, and plague, among other infectious diseases.

The authors state that these outbreaks, which occurred during the strong ENSO event of 2015-2016, affected regions including Southeast Asia, Tanzania, the western United States, and Brazil. Changes in precipitation, temperature, and vegetation caused excessive droughts and floods, creating favorable ecological conditions for the emergence and spread of pathogenic microorganisms and their vector transmitters in these regions.

The researchers demonstrated that the intensity of diseases in some regions teleconnected with ENSO doubled compared to years when this climatic event did not occur (Anyamba et al., 2001, 2019). Dengue in Brazil and Southeast Asia is also associated with higher-than-normal land surface temperatures (Anyamba et al., 2001, 2019; Coelho-Cruz et al., 2023). An increase in temperature above the usual levels, closely related to increased humidity, shortens the development cycles of vectors, subsequently increasing vector density. This rise in vector population density leads to greater mosquito-human interaction, resulting in arboviral diseases such as Dengue, Chikungunya, Zika, and even urban yellow fever, due to the domestic habits of the vector. Consequently, the number of cases could be expected to double.

Table 2. Articles Found in Databases, Classified by Type of Infectious Disease Classified by type of infectious disease: viral, bacterial, parasitic, and fungal. Specified by infectious pathology, article title, author, year of the El Niño-Southern Oscillation (ENSO) event during which the study was conducted, associated causes and effects, and conclusions.

N°	Article title	Author	Diseases	Year of the El Niño Phenomenon	Cause /Effect	Conclusion
			Viral Diseases			
1	**Spatiotemporal clustering, climate periodicity, and social-ecological risk factors for dengue during an outbreak in Machala, Ecuador, in 2010**	Stewart-Ibarra et al. (2014)	Dengue	2009-2010	Precipitation, abnormally high temperatures associated with dengue outbreaks	The presence of the *Ae. aegypti* mosquito is associated with temperature and abundant rainfall. In 2010, during the peak of the Dengue season (February-March), rainfall was almost double the normal. This increased the availability of habitat for mosquito larvae. Fluctuations in rainfall and temperature influences the rate of mosquito oviposition and virus replication.
2	**El Fenómeno ENOS y el dengue, Regiones Pacífico Central y Huetar Atlántico, Costa Rica, 1990 a 2011**	Ramírez-Solano et al. (2017)	Dengue	1990-2011	El Niño (warm phase) increased the incidence of dengue in the Pacific and decreased in the Caribbean. La Niña (cold phase) increased the incidence of dengue in the Caribbean and decreased in the Pacific.	The El Niño Southern Oscillation (ENSO) phenomenon affects the increase or decrease of dengue cases. In Costa Rica, during the warm season, the cumulative incidence of dengue fever increased in the Pacific Ocean zone and decreased in the Caribbean Sea zone. La Niña has the opposite effect.
3	**Effects of local and regional climatic fluctuations on dengue outbreaks in southern Taiwan**	Chuang et al. (2017)	Dengue	1998-2015	Temperature, rainfall and high humidity increased dengue transmission	Dengue transmission can be affected by regional and local climatic factors.
4	**Climate change and dengue fever transmission in China: Evidences and challenges**	Li et al. (2016)	Dengue	2018	Extreme El Niño weather conditions affect the survival, replication and development of dengue virus and mosquito vectors.	Climatic factors temperature, precipitation, humidity, wind speed and atmospheric pressure can affect the spread of dengue because all these factors impact the survival of the virus, the mosquito vector and modify the dengue transmission environment.
5	**Influencia del evento climático El Niño sobre la dinámica de transmisión de dengue en Medellín, Antioquia, Colombia**	Rúa-Uribe et al. (2013)	Dengue	2002-2010	El Niño climate variability influences disease incidence by affecting vector population dynamics and the extrinsic incubation period of the virus.	It has been shown that although the dynamics of dengue transmission is a multicausal event, the potential impact of macro-climatic variables such as the increase in sea level temperature caused by the El Niño phenomena on the incidence of dengue in Medellín Colombia has been demonstrated.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
6	**Spatial Hierarchical Analysis of the Temporal Influences of the El Niño-Southern Oscillation and Weather on Dengue in Kalutara District, Sri Lanka.**	Liyanage et al. (2016)	Dengue	2009-2013	Increase in temperature has influenced the cases of dengue fever.	Study showed strong association between climate, El Niño-Southern Oscillation and dengue in Sri Lanka.
7	**ENSO-driven climate variability promotes periodic major outbreaks of dengue in Venezuela**	Vincenti-Gonzalez et al. (2018)	Dengue	1991-2016	High temperatures and low rainfall increase dengue cases.	The study findings provide significant evidence of the relevant climate effect on dengue dynamics. The local and regional climatic factors studied here should be included in an early warning system for dengue and other *Ae.eegypti* in Venezuela.
8	**Impacts of El Niño Southern Oscillation on the dengue transmission dynamics in the Metropolitan Region of Recife, Brazil**	Dos Santos Ferreira et al. (2022)	Dengue	2001-2017	Temperature abnormalities and reduced rainfall favored the mosquito's life cycle.	The dengue epidemic coincided in the Recife region with the El Niño Southern Oscillation (ENSO) phenomenon, spread regionally and was very synchronized.
9	**The effect of weather and climate on dengue outbreak risk in Peru, 2000-2018: A timeseries analysis**	Dostal et al. (2022)	Dengue	2000-2018	Positive impact between temperature increases and dengue outbreaks in Peru.	The results obtained provide strong evidence that temperature and the El Niño Southern Oscillation (ENSO) have significant effects on dengue.
10	**Seasonal patterns of dengue fever in rural Ecuador: 2009-2016**	Sippy et al. (2019)	Dengue	2009-2016	High temperatures increase the number of dengue cases. Precipitation and flooding cause mosquito eggs to hatch and periods of drought also favor breeding sites.	This is the first report on the long-term seasonality of dengue in Ecuador, one of the few studies using daily disease reports.
11	**Global risk model for vector -borne transmission of Zika virus reveals the role of El Niño 2015**	Caminade et al. (2017)	Zika	2015-2016	Warm temperatures associated with the El Niño phenomenon favored mosquito-borne transmission of Zika throughout 2015.	The risk of Zika transmission in South America in 2015 was the highest since 1950. It was found that temperature favors the biting rate and the intrinsic incubation period of the vector. South America and tropical countries present higher level of transmission where *Ae. Aegypti* is more abundant. There is a risk of Zika transmission in the United States, China and Europe.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
12	**Climate Variability, Vulnerability, and Natural Disasters: A Case Study of Zika Virus in Manabi, Ecuador Following the 2016 Earthquake**	Sorensen et al. (2017)	Zika	2016	Fluctuations in temperature and precipitation. High vector densities during the rainy season.	In Ecuador, after El Niño 2016, the trigger of a natural disaster during abnormal weather and underlying social vulnerabilities multiplied the force that contributed to a dramatic increase in ZIKV cases after the earthquake.
13	**Post-earthquake Zika virus surge: Disaster and public health threat amid climatic conduciveness**	Reina Ortiz et al. (2017)	Zika	2015-2016	Variations in temperature, changes in precipitation, humidity and atmospheric pressure. Ecological changes caused by the 2016 earthquake in Ecuador.	This study provides critical information to help prevent public health pooing in densely populated areas of North America, Europe and Australia where rising temperatures may be within the range of mosquito vectors of this disease.
14	**An Ecological Assessment of the Pandemic Threat of Zika Virus.**	Carlson et al. (2016)	Zika	2015- 2016	Precipitation and diurnal fluctuations in temperature may limit transmission of Zika.	Comparison of Zika's habitat with the known distribution of dengue suggests that Zika is more limited by seasonal rainfall and temperature variations which could limit non-sexual indigenous transmission of this virus.
15	**Analyzing climate variations at multiple timescales can guide Zika virus response measures**	Muñoz et al. (2016)	Zika	2015-2016	Severe droughts and very high temperatures favor the cases of Zika.	High temperatures helped set the climate scenario for Zika virus transmission.
16	**Environmental Changes and the Impact on the Human Infections by Dengue, Chikungunya and Zika Viruses in Northern Brazil, 2010–2019**	Marinho et al. (2022)	Dengue Chikungunya Zika	2010-2019	High temperatures were correlated with Zika cases in Brazil between 2014 and 2016. The increase in precipitation and temperature caused by La Niña between 2015 and 2016 increased Chikungunya infections.	This study found that deforestation and climate change had a strong influence on infections caused by Dengue, Chikungunya and Zika viruses.
17	**Prediction of a Rift Valley fever outbreak**	Anyamba et al. (2009)	Rift Valley fever	2006-2007	Heavy rainfall favors vegetation growth, creating an ideal habitat for the mosquito vector of the virus.	The convergence of ENSO conditions in the eastern Pacific and the simultaneous warming of the temperature above sea level in the western equatorial region of the Indian Ocean was the triggering mechanism for the outbreak of Rift Valley fever. In East Africa, ENSO was found to have a major influence on this disease.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
18	**Climate Conditions During a Rift Valley Fever Post-epizootic Period in Free State, South Africa, 2014–2019.**	Anyamba et al. (2022)	Rift Valley fever	2014-2019	High rainfall periods, cooler than normal conditions and abundant vegetation.	Climatic factors influenced by the El Niño phenomenon, rainfall, humidity, vector detection, surveillance in high-risk areas and vaccination campaigns should be methods for preventing this disease.
19	**NDVI anomaly patterns over Africa during the 1997/ 98 ENSO warm event**	Anyamba et al. (2001)	Rift Valley fever	1997-1998	Extensive flooding created the conditions for the proliferation of this disease.	El Niño recorded between 1997-1998 was the strongest on record in the 20th century. By causing flooding and creating conditions that favored some diseases affecting livestock and humans in East Africa, forecasting tools could provide early warning to these regions to avoid the transmission of infectious diseases.
20	**Investigation of the Correlation between Enterovirus Infection and the Climate Factor Complex Including the Ping-Year Factor and El Niño-Southern Oscillation in Taiwan**	Yu et al. (2024)	Enterovirus	2007-2022	Enterovirus correlates with temperature, humidity, precipitation, wind speed, with temperature being the most important climatic factor affecting the prevalence of this disease.	El Niño significantly impacted the incidence of enterovirus infections in Taiwan.
21	**Short-Term Effect of El Niño-Southern Oscillation on Pediatric Hand, Foot and Mouth Disease in Shenzhen, China**	Lin et al. (2013)	Enterovirus	2008-2010	Humidity and temperature were associated with an increase in this disease.	Meteorological factors could be important predictors of the occurrence of pediatric hand-foot-and-mouth disease in Shenzhen.
22	**Emerging and re-emerging viruses in Malaysia, 1997—2007**	Tee et al. (2009)	Enterovirus	1997-1998	Drought conditions, temperature increase due to the El Niño Southern Oscillation (ENSO) phenomenon.	Anthropogenic factors such as agricultural encroachment or expansion confounded with the temporal and spatial dynamics of both viruses and hosts and their immunity have been linked to outbreaks of viral infections in Malaysia, Bangladesh and India. Therefore, to avoid the re-emergence of viruses or zoonoses, deforestation and agricultural intensification activities must be regulated.
23	**Effect of non-stationary climate on infectious gastroenteritis transmission in Japan**	Onozuka (2014)	Infectious gastroenteritis	2000-2012	These infections are strongly associated with changes in temperature, humidity and precipitation.	Quantitative evidence was found that environmental changes caused by the El Niño and Indian Ocean dipole phenomena are associated with the prevalence of infectious gastroenteritis. Early warning systems should be developed for epidemics caused by this disease.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
24	**Seasonal Influenza Epidemics and El Niños**	Oluwole (2015)	Influenza	2000-2015	Seasonal influenza severity increased during El Niño and decreased during La Niña.	The severity of the influenza epidemic with the strength and waveform of the El Niño phenomenon indicates that models forecasting this phenomenon should be integrated into the health surveillance program focused on the prevention of influenza epidemics.
25	**Dynamic Regimes of El Niño Southern Oscillation and Influenza Pandemic Timing.**	Oluwole (2017)	Influenza	2009-2020	Low temperatures and precipitation favor aerosol transmission of influenza. The virus is sensitive to temperature.	Coupling of all influenza pandemics over the past 140 years to chaotic low-transitivity regimes indicates that ENSO dynamics drive the prevalence of influenza pandemic infection.
26	**How do El Niño Southern Oscillation (ENSO) and local meteorological factors affect the incidence of seasonal influenza in New York state?**	Xiao et al. (2022)	Influenza	2015-2018	It is highly correlated with temperature and humidity anomalies caused by El Niño.	Low ENSO index, low temperature and absolute humidity may drive influenza epidemics in New York.
27	**The El Niño–Southern Oscillation (ENSO) –pandemic Influenza connection: Coincident or causal?**	Shaman and Lipsitch (2013)	Pandemic Influenza	1918-1920 1957-1958 1968-1969 2009-2010	Birds are the carriers of the influenza virus, and an association was observed during La Niña between the influenza pandemic and changes in bird migration caused by ENSO.	It was shown that influenza virus can emerge in the human population in other places due to the transport of migratory birds and the movement of the virus should be considered from geographies where the El Niño phenomenon is frequent.
28	**Association of early annual peak influenza activity with El Niño southern oscillation in Japan. Influenza Other Respir. Viruses**	Zaraket et al. (2008)	Influenza	1983-2007	Evident relationship between peak activity of influenza viruses and the El Niño Southern Oscillation ENSO phenomenon.	There are clear complexities in trying to understand the relationships between climate change and disease patterns such as influenza.
29	**Can El Niño–Southern Oscillation Increase Respiratory Infectious Diseases in China? An Empirical Study of 31 Provinces.**	Tang et al. (2022)	Influenza	2007-2018	The 2015-2016 El Niño event caused severe drought and extreme temperatures favoring the influenza virus in China.	Improve the climate early warning system on respiratory infectious diseases in China to control the spread of respiratory infectious diseases.
			Bacterial Diseases			
30	**La correlación entre tres teleconexiones y la incidencia de leptospirosis en el distrito de Kandy, Sri Lanka, 2004-2019**	Ehelepola et al. (2021)	Leptospirosis	2004-2019	La Niña period and high rainfall were associated with the prevalence of leptospirosis.	Monitoring of extreme teleconnection events such as El Niño and La Niña and improvements in flood prevention measures in Sri Lanka could mitigate leptospirosis spikes that may occur.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
31	**Quantifying the relationship between climatic indicators and leptospirosis incidence in Fiji: A modelling study**	Rees et al. (2023)	Leptospirosis	2006-2017	Heavy rainfall leads to increased incidence of leptospirosis.	This study could identify that climatic factors influence the risk of leptospirosis transmission in Fiji.
32	**Climatic Variability and Human Leptospirosis Cases in Cartagena, Colombia: A 10-Year Ecological Study**	Cano-Pérez et al. (2022)	Leptospirosis	2008-2017	Precipitation and humidity during the La Niña phenomenon were correlated with the increase of cases.	The climate in Cartagena (Colombia) favors the incidence of leptospirosis. Prevention and control of this disease in the city should be promoted and strengthened.
33	**Changes in epidemiology of leptospirosis in 2003–2004, a two El Niño Southern Oscillation period, Guadeloupe archipelago, French West Indies**	Storck et al. (2008)	Leptospirosis	1994-2001	Relationship between exceptional meteorological events such as El Niño phenomenon and its influence on the population of leptospirosis-transmitting rodents. There is a positive correlation between precipitation and leptospirosis..	Changes in the epidemiology of leptospirosis in the tropical island of Guadeloupe are highly related to climatic conditions, with a high potential for a rapid outbreak of transmission and a possible impact on the serogroups responsible for the infection, and the clinical characteristics of the disease in the human population.
34	**El Niño Southern Oscillation and Leptospirosis Outbreaks in New Caledonia.**	Weinberger et al. (2014)	Leptospirosis	2000-2012	There is a significant association between leptospirosis cases and each of the El Niño indices such as rainfall and sea surface temperature anomalies.	Leptospirosis outbreaks should be predicted as of paramount importance for public health decision-makers to implement preventive measures, such as rodent control, riverbank cleanups, and sewage systems to avoid flooding.
35	**The interrelationship between meteorological parameters and leptospirosis incidence in Hambantota district, Sri Lanka 2008–2017 and practical implications.**	Ehelepola et al. (2021)	Leptospirosis	2008-2017	High soil temperatures, evaporation rate, light duration, and high rainfall coincided with increased prevalence of this disease.	Favorable weather contributed to the to the 2011 leptospirosis outbreak. It represents the first long-term study to show that soil temperature, evaporation rate and climatic phenomenon such as the Indian Ocean dipole rather than El Niño are correlated with leptospirosis in Sri Lanka.
36	**Towards a leptospirosis early warning system in northeastern Argentina**	Lotto Batista et al. (2023)	Leptospirosis	2009-2020	Floods related to the El Niño phenomenon are associated with leptospirosis.	Climatic events are strong drivers of leptospirosis incidence in Argentina.
37	**Extreme water-related weather events and waterborne disease**	Cann et al. (2013)	Vibrio cholera	1995-2005	ENSO and extreme temperature changes favor the prevalence of cholera.	Rising global temperature will increase prevalence of waterborne diseases.
38	**Cholera forecast for Dhaka, Bangladesh, with the 2015-2016 El Niño: Lessons learned**	Martinez et al. (2017)	Cholera	2015-2016	Rainfall and flooding associated with cholera.	There is a teleconnection between the El Niño Southern Oscillation (ENSO) and cholera in Bangladesh.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
39	**The Impact of El Niño on Diarrheal Disease Incidence: A Systematic Review**	Solomon and Bezatu (2017)	Cholera (Diarrhea)	2002-2016	ENSO associated with drought and flooding increase risk of diarrheal diseases worldwide.	A systematic review in which many studies showed a significant association between diarrheal diseases and El Niño. However, research on the impact of El Niño or climatic change in diarrheal diseases are limited.
40	**Cholera and Shigellosis: Different Epidemiology but Similar Responses to Climate Variability**	Cash et al. (2014)	Cholera and Shigellosis	1985-2005	El Niño has been shown to cause favorable conditions for the increase of Cholera, as well as increased rainfall that causes flooding favorable for the proliferation of Cholera and Shigellosis.	Cholera and Shigellosis are diarrheal diseases whose causative organisms differ in their ecology, transmission routes, dosage and other characteristics. In Bangladesh, inter-annual variations in the outbreaks of infection of both diseases were shown to be related to flooding caused by heavy rainfall due to El Niño phenomenon.
41	**Effects of El Niño/La Niña on the Number of Imported Shigellosis Cases in the Republic of Korea, 2004–2017**	Kim et al. (2021)	Shigellosis	2004-2017	Shigellosis is considered sensitive to climate; its incidence increases with the onset of droughts and floods.	The incidence of Shigellosis in travelers causes Shigellosis outbreaks in Southeast Asia, so it can be expected that Shigellosis cases will increase significantly among international tourists visiting Korea during the La Niña period.
42	**Interannual Variability of Human Plague Occurrence in the Western United States Explained by Tropical and North Pacific Ocean Climate Variability**	Ben Ari et al. (2010)	Plague (*Yersinia pestis*)	1950-2005	Precipitation and high temperatures affect both hosts and vectors transmitting plague. Snow is also key as soil moisture aids the survival and development of plague-transmitting fleas, and vegetation growth favors rodents.	The increase in temperature caused by climate change will decrease soil moisture, which could decrease the survival and development of the flea that transmits plague and could lead to a decrease of this disease in the southwestern United States, but it could increase in New Mexico.
43	**A Non-Stationary Relationship between Global Climate Phenomena and Human Plague Incidence in Madagascar**	Kreppel et al. (2014)	Plague	1960-2008	They found a relationship between El Niño, the Indian Ocean dipole phenomenon, temperature, precipitation, and plague incidence.	This study demonstrates the complex and changing relationship between climate factors and plague in Madagascar.
			Parasitic Diseases			

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
44	**Effects of El Niño-Southern Oscillation on human visceral leishmaniasis in the Brazilian State of Mato Grosso do Sul**	Da Silva et al. (2020)	Human visceral leishmaniasis	2002-2015	Variations in temperature and the incidence of precipitation on humidity are associated with the incidence of visceral Leishmaniasis in Brazil. Vectors are influenced by temperature, humidity, luminosity, altitude and vegetation, all of which influence parasite transmission.	This study determined that the occurrence of extreme climatic phenomena, such as El Niño and La Niña phases, can significantly influence the incidence of visceral leishmaniasis. The authors demonstrated that El Niño reduces the incidence of Leishmaniasis and La Niña is believed to increase it.
45	**Cutaneous Leishmaniasis and Sand Fly Fluctuations Are Associated with El Niño in Panama**	Chaves et al. (2014)	Cutaneous leishmaniasis	2000-2010	ENSO precipitation and temperature are associated with this disease.	There is an association between ENSO and cutaneous Leishmaniasis. The variability of temperature and precipitation in Panama is associated with the vector that could cause an epidemiological outbreak.
46	**Extreme water -related weather events and waterborne disease**	Cann et al. (2013)	*Cryptosporidium*	1995-2010	Extreme weather conditions, related to contaminated water.	Waterborne pathogen from environmental exposures following extreme climatic conditions.
47	**Infectious Disease Sensitivity to Climate and Other Driver-Pressure Changes: Research Effort and Gaps for Lyme Disease and Cryptosporidiosis**	Ma et al. (2023)	*Cryptosporidiasis*	2000-2022	Sensitivity to climate and environmental factors temperature and rainfall.	Improve the availability of data to mitigate infectious diseases associated with climate variability.
48	**Effects of the 1997–1998 El Niño Episode on Community Rates of Diarrhea**	Bennett et al. (2012)	Cyclospora gayetanensis	1997-1998	High temperatures and low humidity increased the prevalence of diarrhea.	They highlighted the importance of considering pathogens, seasonality, infrastructure, water sanitation and also the effects of climate change in order to predict catastrophic climatic events such as El Niño on public health and thus be able to predict and anticipate in order to mitigate the risks of diarrhea in vulnerable communities.
			Fungal diseases			
49	**Climate drivers of hospitalizations for mycoses in Brazil**	Brito-Silva et al. (2019)	Mycosis	2008-2016	La Niña Phenomenon Climate modulates mycosis hospitalizations with minimum temperatures as a climatic variable.	The influence of the Pacific climatic oscillation was observed, specifically the low temperatures of La Niña, on the prevalence of mycosis in Brazil.
50	**Expansion of Coccidioidomycosis Endemic Regions in the United States in Response to Climate Change**	Gorris et al. (2019)	Coccidiomicosis	2019	Increased temperature and precipitation may alter the endemic regions of this disease.	It was determined that the endemic area of this disease, as well as the number of cases per year, will increase in response to climate change.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
51	**Coccidioidomycosis (Valley Fever), Soil moisture, and El Niño Southern Oscillation in California and Arizona.**	Tobin et al. (2022)	Coccidiomicosis	2009-2012	Fungal infection associated with soil moisture states. There is a moderate but significant connection with El Niño.	This study provides an example of how ocean-atmospheric teleconnections can affect human health.
Other articles on infectious diseases and the El Niño Southern Oscillation (ENSO) phenomenon						
52	**Infectious Diseases: Research and Treatment**	Anderson (2010)	Chikungunya, Dengue, Malaria, Cholera, Rift Valley fever, respiratory diseases, Lyme disease, cutaneous Leishmaniasis.	2005-2006	Drought favored the conditions of the vector causing Chikungunya.	Education focused on environmental health is incorporating community and cultural aspects to reduce the risks of infections caused by mosquito vectors that increase in number during extreme weather events.
53	**Reflections on the impact and response to the Peruvian 2017 Coastal El Niño event: Looking to the past to prepare for the future.**	Yglesias-González et al. (2023)	Dengue, Cholera Yellow fever, Malaria, Zika, Leptospirosis, diarrhoeal diseases, respiratory diseases and pneumonia.	2012-2017	The 2017 coastal El Niño in Peru presented conditions called neutral to cold. El Niño caused an increase in rainfall and flooding of rivers, creating strong impacts on health. Increase in infectious and vector-borne diseases.	The coastal El Niño of 2017 was intense and abrupt, which increased heavy rains and floods tenfold, similar to the effects of the 1983 and 1998 El Niño. An increase in infectious and vector-borne diseases was observed, with the largest outbreak of dengue fever ever recorded in Peru and an increase in cases of leptospirosis during the study period.
54	**El Niño and human health**	Kovats (2000)	Dengue, Australian Encephalitis, Ross River virus, Rift Valley fever, Hantavirus, Cholera, Shigellosis, Typhoid.	1997-1998	Extreme weather conditions causing floods and droughts provoked by the ENSO cycle associated with mosquito and rodent-borne diseases.	There is epidemiological evidence that the El Niño phenomenon is associated with risk of transmission of some diseases in specific geographic areas where climatic anomalies are associated with the El Niño event.
55	**Global Disease Outbreaks Associated with the 2015–2016 El Niño Event**	Anyamba et al. (2019)	Cholera, Dengue, Chikungunya, Hantavirus, Malaria, Rift Valley fever, respiratory diseases, Ross River virus disease	2015-2016	The extreme temperature and precipitation caused by El Niño.	It is evident that the extreme weather conditions caused by the El Niño phenomenon are closely associated with a high risk of infectious disease transmission.
56	**Multiple impact pathways of the 2015–2016 El Niño in coastal Kenya**	Fortnam et al. (2021)	Cholera, Malaria, Rift Valley fever, Dysentery, Diarrhea.	2015-2016	The floods led to conditions suitable for an increase in vector-borne diseases.	Social, ecological and health vulnerability to El Niño and other extreme weather events demonstrated in Kenya.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
57	**Influencia de factores climáticos sobre las enfermedades infecciosa**	Huarcaya Castilla et al. (2004)	Malaria, Dengue, Bartonelosis, Leishmaniasis, Diarrhea, Cholera, Plague Hantavirus, Ringworm, Pityriasis versicolor, Folliculitis, Pyodermitis, Dermatitis, Cryptosporidiosis, Lyme disease.	1973-1998	Climate changes caused by El Niño and human migrations have increased the number of cases of these diseases.	Advances in molecular biology and mathematical modeling analysis have been improving our understanding of the biological explanations for infectious diseases, allowing the opportunity to predict outbreaks of infectious disease in areas at risk to obtain the biological explanations for infectious diseases, allowing to predict outbreaks of infectious disease infections in areas at risk to climate variability.
58	**Climate and Infectious Diseases**	Kelly-Hope and Thomson (2008)	Malaria, Dengue, Meningitis, Meningococcus, Esquistosomiasis, Rotavirus, Leishmaniasis.	1880-1998	Indices that determine El Niño events have been associated with diseases such as Leismaniasis in Brazil, Malaria in Ghana, and Rift Valley fever in Australia.	This review provides a platform from which to launch future research and policy development in relation to climate-sensitive diseases, and suggests that vulnerable countries should be the focus of this research.
59	**Climate change and infectious diseases**	Flahault et al. (2016)	Rift Valley fever, Cholera, Malaria, Dengue, Chicungunya, Zika, Yellow fever, Flu or influenza.	2004-2016	In East Africa, El Niño-induced excess humidity linked to increase in Rift Valley Fever cases.	Climate scientists have recently observed that climate change is linked to more frequent and intense El Niño events. Increases in the frequency and severity of emerging infectious, vector-borne and airborne diseases in the world can be expected.
60	**Climate variability and water-related infectious diseases in Pacific Island Countries and Territories, a systematic review**	Hosking et al. (2023)	Cholera, Typhoid fever, Cryptosporidiasis, Dengue, Malaria, Diarrhea, Leptospirosis, Chicungunya, Zika, Hepatitis A.	2022	Temperature, precipitation and humidity as key factors in dengue transmission.	The water supply and hygiene system must be strengthened to reduce infectious diseases during extreme weather events.
61	**Impact of El Niño Southern Oscillation on infectious disease hospitalization risk in the United States**	Fisman et al. (2016)	Vector-borne diseases, Pneumonia and Influenza, enteric diseases, zoonotic bacterial diseases, fungal diseases.	1970-2010	High rainfall and temperatures, very wet or dry conditions increase the risk of enteric diseases.	It is demonstrated the importance of understanding the links between the environment and infection risks when environmental conditions are extreme, such as during El Niño and the need to invest in public health surveillance capable of detecting changes in disease burdens.

Table 2 – Continuation of the table

N°	Article title	Author	Diseases	year of the El Niño Phenomenon	Cause /Effect	Conclusion
62	**Riesgo de infecciones enfermedades crónicas y trastornos de salud mental con posteridad a inundaciones por el fenómeno del niño costero en poblaciones desplazadas, Piura, 2017.**	Loayza-Alarico and De La Cruz-Vargas (2021)	Skin infection, Urinary tract infection, joint paint, diabetes mellitus, diarrheal diseases, arterial hypertension.	2017	Natural disasters such as floods that modify vector ecosystems.	At the onset of natural disasters caused by El Niño, epidemiological profiles show the presence of psychological effects and the transmission of infectious diseases, and over time chronic diseases such as diabetes appear.
63	**Time-Series Study of Associations between Rates of People Affected by Disasters and the El Niño Southern Oscillation (ENSO) Cycle.**	Lam et al. (2019)	Zika, Dengue, Cholera, Hantavirus, Malaria	1964-2017	The El Niño Southern Oscillation (ENSO) phenomenon causes the increase of these diseases.	The relationships between El Niño cycles and population health burdens are related to natural disasters caused by climatic anomalies. These can help to improve disaster preparedness strategies and prevent the decrease of morbidity and mortality records caused by infectious diseases.

3.3 El Niño Phenomenon and bacterial diseases

In the case of leptospirosis, research by Weinberger et al. (2014) on the relationship between ENSO and leptospirosis in New Caledonia shows that this disease exhibits seasonal outbreaks in the tropics. Using time series data from 2000 to 2012, the authors evaluated whether climatic factors such as ENSO and meteorological conditions can predict leptospirosis outbreaks. They found that periods coinciding with La Niña were associated with abundant precipitation, which in turn was related to outbreaks of this disease. Their study demonstrated a strong association between ENSO and leptospirosis, suggesting that similar studies should be replicated in regions of the South Pacific, Asia, or Latin America where El Niño also induces climatic variability that poses a risk of outbreaks. Leptospirosis cases were above the annual average observed from 2012 to 2016. However, the incidence of other diseases sensitive to ENSO, with shorter incubation periods such as acute respiratory infections, diarrhea, and pneumonia, was lower than the reported during 2012-2016 (Weinberger et al., 2014).

Leptospirosis outbreaks are closely related to climatic events like floods caused by heavy rainfall, considered a risk factor associated with the disease. For example, plague outbreaks in Colorado and New Mexico are linked to abnormal precipitation (Anyamba et al., 2019). Plague is caused by *Yersenia pesti*, a zoonotic bacterium found in small mammals and their parasitic fleas. Abundant winter precipitation followed by hot summers leads to increased flea production, as noted by the authors.

Additionally, heavy rainfall influences the contamination of surface water with sewage, representing common causes of diarrhea associated with contaminated water supplies and floods, directly impacting the transmission of typhoid fever and shigellosis. Typhoid fever is common where sanitation is poor and potable water is unavailable, similar to conditions for shigellosis. In areas without water supply, events like heavy rainfall often lead to unusual outbreaks of these diseases due to contamination of drinking water with sewage (Anyamba et al., 2001, 2019).

Kim et al. (2021) studied the effects of El Niño and La Niña on the number of shigellosis cases in Korea from 2004 to 2017. They demonstrated that the risk of shigellosis infection increased with the rise in La Niña index, as fluctuations caused by La Niña in South and Southeast Asian countries affect water sanitation.

Floods and ENSO cannot be directly related to disease transmission. However, droughts can be linked to increased pathogens in surface water and hygiene-related diseases. ENSO-induced temperature increases directly influence gastrointestinal infections. For instance, the 1997-1998 El Niño in Peru caused temperature rises that resulted in a significant number of children being hospitalized with diarrhea (Kovats, 2000).

Solomon and Bezatu (2017) conducted a systematic review on the impact of El Niño on the mortality and morbidity of diarrheal diseases. This study found a significant relationship between ENSO and these diseases. Childhood diarrheal diseases cause morbidity and mortality in developing countries, and ENSO has been shown to affect the dynamics of diarrhea incidence in South America and Asia. However, the effects of this event on diarrhea in sub-Saharan Africa, where the burden of diarrheal infections among children under five is highest, are not well understood. Diarrhea is a leading cause of mortality in Africa due to the lack of water and basic services.

Diarrhea usually occurs due to infections caused by rotavirus or bacteria, leading to the deaths of thousands of children due to the loss of salts, electrolytes, and nutrients. Southern Africa and Southwest Asia account for nearly 80% of all diarrhea-related deaths globally, possibly linked to the lack of nutrient-rich water, exacerbating the epidemiological situation in these children. ENSO is characterized by a warming period of sea surface temperatures and the consequent suppression of nutrient-rich cold water currents, which follows the pattern observed off the coasts of Peru and Ecuador and generally lasts between 12 and 18 months.

Regarding enteric diseases in the western United States, a decrease in this pathology was observed, with increased risk in other regions of the country. Thus, both wet and dry conditions increase the risk of enteric diseases (Fisman et al., 2016).

3.4 El Niño Southern Oscillation and parasitic and fungal diseases

Climate change triggers extreme weather events that have been associated with parasitic diseases worldwide, with leishmaniasis being one of the most studied. Da Silva et al. (2020), in their research on the effect of ENSO on human visceral leishmaniasis, mention that the increase in visceral leishmaniasis cases in Panama was associated with the cold phase of ENSO. They also note that factors influencing the variation in the number of visceral leishmaniasis cases in Brazil include environmental variables such as temperature, light, humidity, altitude, and vegetation cover. These factors can influence the transmission of the parasite and the development of the disease.

Regarding *Cryptosporidium*, Cann et al. (2013) mention that most outbreaks of parasitic diseases occurred after extreme water-related weather events, such as severe storms, heavy rains related to ENSO, cyclones, seawater flooding, hurricanes, or tides. After an extreme weather event, the probable causes of parasitic infections could be water contamination, scarcity of potable water, and poor sanitation and hygiene.

In Peru, it was reported that most of the population affected by floods presented skin diseases, mainly among children. The most frequent cases included infections, excoriations or superficial wounds, allergic dermatitis, pyodermatitis, mycoses, among other pathologies (MSP/OPS, 1989). However, there are few studies that reveal the effect of ENSO as a trigger for mycoses. To evaluate coccidioidomycosis in the United States, a soil-borne fungal disease common throughout the southwestern U.S. and related to soil moisture, Tobin et al. (2022) analyzed the correlation between ENSO, soil moisture, and coccidioidomycosis incidence from 2009 to 2012. They observed a moderate and significant connection between ENSO, soil moisture, and coccidioidomycosis. The authors demonstrated that ocean-atmosphere teleconnections could affect human health.

Gorris et al. (2019), in their study on the expansion of coccidioidomycosis in endemic regions of the United States in response to climate change, determined that elevated temperatures could shift the location of this fungal disease from the southeastern U.S. to also affect the western part of the country. By 2100, the west is expected to become hotter and more affected by rain, conditions that favor the fungus and could double the number of affected individuals in the country. The Coccidioides fungus thrives in areas with little rainfall and high temperatures, so when soil moisture is high, accompanied by high temperatures, it favors the dispersion and transmission of the fungus, as observed between 2009 and 2012, facilitated by ENSO.

As previously noted, ENSO events may become more frequent due to climate change. Although El Niño events are global, the magnitude of their impact varies, with some regions considered teleconnected to ENSO. This means they experience climatic anomalies related to ENSO despite being thousands of kilometers away, while other regions are not teleconnected (Fisman et al., 2016).

3.5 Strengths and Limitations

This study focused on research regarding infectious diseases and the influence of climatic anomalies caused by ENSO, conducted between 2000 and 2023. It included the strong El Niño-Southern Oscillation events of 1982-1983, 1997-1998, and 2016-2017. The geographical areas selected for the research were those vulnerable to El Niño events, where studies on epidemics or infectious diseases had been conducted. The search terms were very broad, and some articles were excluded because they dealt with general infectious diseases, such as diarrhea, which can be caused by bacteria, parasites, or viruses, or respiratory diseases without specifying the causative microorganism.

For viral infectious diseases like Zika and Chikungunya, few studies were found for the years 1982-1983 and 1997-1998. Similarly, few studies on parasitic or fungal diseases met the inclusion criteria. The broad search terms and the search for complete citations may have overlooked important literature. Additionally, possible biases could have arisen from not conducting a more exhaustive meta-analysis. Limited data availability and heterogeneous climatic indicators should also be considered.

Furthermore, the vulnerable geographical areas are typical in developing countries that do not generate data or research comparing epidemiological cases with environmental or climatic data. More research is recommended on the influence of extreme climatic variables under ENSO, which generally leads to catastrophes like wildfires, floods, and droughts, usually resulting in an increase in viral, bacterial, parasitic, and fungal diseases.

There is a need to determine the nature of ecological mechanisms and their relationship with diseases, analyzing the ecological foundations of diseases. Links should be established between health professionals, policy makers, and meteorological predictors to predict long-term epidemiological risks in areas vulnerable to extreme climatic factors. Additionally, early epidemiological alerts should be created to mitigate the proliferation of diseases caused by viruses, bacteria, parasites, and fungi.

4 Conclusions

The climatic variability caused by ENSO promotes the emergence of imported infectious diseases, which can become endemic rather than being eradicated. The projected consequences of diseases resulting from ENSO will vary depending on how the phenomenon manifests (flooding, drought, temperature increase, or heavy precipitation).

To forecast the repercussions in different endemic areas due to ENSO, it is imperative to consider risk factors, climate variability, and the geographical context. These factors should be integrated with programs that control infectious diseases. Attention should be focused on the climate and the necessity for programs to adapt and identify changes in morbidity and mortality induced by the climate. This will help stratify the risk of these diseases influenced by climatic variations, aiding in decision-making.

It is crucial to better understand the links between the environment and the risk of infection in various regions to establish working groups, perhaps prioritizing the most prevalent infectious diseases in the region.

Author contribution

P.M.: Conceptualization, Data processing, Data curation, Methodology, Visualization, Writing- original draft, Writing- review and Editing; G.V.S.: Conceptualization, Conceptualization, Data processing, Data curation, Methodology, Visualization, Writing- original draft, Writing- review and Editing.

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