EL NIÑO AND VECTOR-BORNE DISEASES

Shweta Rana
Shweta Rana, Associate Professor/Dept. of Physical &Natural Sciences,FLAME University, Pune, Maharashtra
Tirtha Patel
Tirtha Patel, Student of Environmental Studies, FLE, FLAME University, Pune, Maharashtra

Abstract: El Niño Southern Oscillation (ENSO) is the most important cyclic climatic phenomenon as it is capable of influencing temperature and precipitation across the globe. ENSO leads to direct and indirect consequences like climate change and natural disasters. Anthropogenic factors too lead to climate change and hence enhance the frequency and intensity of local weather changes. El Niño causes tremendous loss of human life and property as well as biodiversity. The extensive loss of biodiversity results in the dilution of the impact of vectors and increased human-vector interaction. The relationship between ENSO and vector-borne diseases is critical due to variability of pathogen, vector, weather, climate and geographical locations. An evidence-based regional approach to understand and explain the correlation using three different case studies: Malaria in Colombia, Dengue in Thailand and Leishmaniasis in Costa Rica is discussed.

Keywords: Biodiversity, Climate Change, El Niño Southern Oscillation, Vector-borne Diseases.

Introduction: El Niño is a weather phenomenon of strong and prolonged warm periods in the Pacific Ocean, causing complex global weather patterns. El Niño is officially declared when the sea surface temperature of the equatorial Pacific Ocean rises by 0.5°C over the historic average, for a period of three consecutive months, along with the related changes in atmospheric conditions and rainfall patterns [17].In 1930s, Sir Gilbert Walker documented and named the recurrent trend of high and low pressures in the East and West Pacific Ocean as the Southern Oscillation, along with using statistical methods to correlate this with various other weather phenomena, with an aim of seasonal forecasting. The correlation between the Southern Oscillation and El Niño was made only in the 1960s, after which this phenomenon was termed as the El Niño Southern Oscillation (ENSO). Herein, ENSO refers to a cycle with two extreme events: El Niño, the warm event (which is usually described as the reversal of the normal scenario) and La Niña, the cold event (which is usually described as an exaggeration of the normal scenario) [22]. Therefore, ENSO as a whole is actually a climate phenomenon, in comparison to its independent elements El Niño and La Niña, which are weather phenomenon [15].The Pacific Trade Winds blow from east to west normally. The east to west Trade Winds weaken during an El Niño. The gradual reversal of Trade Winds causes the warm surface water of the ocean (which normally traveled westwards with the winds) to move eastwards, this in turn result in the warming of the Pacific Ocean eastwards, near the western coast of South America [8]. Pushing the cold, dense, and nutrient-rich water to the bottom of the ocean, the warm water of the ocean rises to the surface leading to decrease in the coastal upwelling of the region. This does not only have climatic repercussions, but also various ecological consequences, as the plankton count falls, causing consecutive implications on fish and sea bird populations. The phenomenon becomes a major economic blow to the fisheries near the western coast of South America [2].ENSO is known to cause devastating effects on biodiversity due to climate change and natural disasters. These lead to direct or indirect propagation of vectors and hence can aid in increased incidences of vector –borne diseases. Taking into account the discrepancies, El Niño events, on an average, occur every two to seven years and last for a continuous period of 12-18 months. However, they vary in their time of onset and intensity. No two El Niño events are the same; they can be distinguished only on the basis of a general cyclic pattern that they occur in [15].

ENSO, Vectors and Health: Vectors are invertebrate animals like ticks, mites, mosquitos, flies, bugs, etc. that are capable of transmitting an infectious agent (pathogen) to the host. Arthropod vectors are cold-blooded and thus especially sensitive to climatic factors. Weather influences survival and reproduction rates of vectors [18]. The subject matter of the relationship between weather (specifically rainfall) and diseases transmitted by vectors, called vector-borne diseases, is well studied. ENSO events increase the likelihood and intensity of the climate change and natural disasters, indicating its indirect correlation with human health. The catastrophic weather changes, during natural disasters, affect and kill millions of people every year, causing not just economic and environmental devastation, but also significant human health loss. The seasonal changes, which are non-catastrophic, are also known to deeply affect human health, as a result of disturbing the human body's homeostasis generating favorable conditions for the growth and survival of pathogens. For instance, during the period of seasonal rainfall, there is an abundance of mosquitoes along with reduced human immunity, causing various vector-borne outbreaks, like Malaria, Dengue, Chikungunya, Zika, etc. [15]. These outbreaks are further intensified during catastrophic weather changes taking place primarily during natural disasters. Droughts, famines, floods, wild fires and tropical storms, initiated by ENSO events, not only cause direct injuries and fatalities, but also malnutrition (due to food insecurity), insurgence of communicable diseases (due to subdued water quality), water-borne diseases (due to lack of safe water supply, hygiene and sanitation), vector-borne diseases (due to increase in the number of vectors), respiratory diseases and heat stress (due to enhanced climatic warming), negative mental health and psychosocial effects, reduced access to health care and disruption of various health-care services (due to the damage caused to the infrastructure). The 2014-16 El Niño affected more than 60 million people in southern and eastern Africa, South America, Pacific Islands and south and southeastern Asia. World Health Organization had announced and urged 30 countries, which were most affected by El Niño and La Nina, to prepare for extreme environmental and health conditions for the La Niña that followed the 2014-16 El Niño [1]. Vector borne diseases aggravate during El Niño as it triggers changed climate patterns, natural disasters and affects biodiversity.

ENSO and Climate Change: Climate Change does not directly affect the frequency of El Niño events but it enhances the frequency and intensity of the weather change caused by it, intensifying its gravity and seriousness on the global economy and human health. The regional warming caused by El Niño further intensifies the gradual increase in global mean temperatures because of various anthropogenic reasons [15]. The relationship between increased atmospheric carbon levels and climate change is well known. Scientists of Orbiting Carbon Observatory-2 satellite of NASA, which measures carbon dioxide levels in the atmosphere, reported that the El Niño of 2014-16 caused over 3 billion tonnes of carbon to get released into the atmosphere, pushing carbon dioxide concentration to record levels. [32]There is great uncertainty with respect to future ENSO trends due to vagueness in its definition and disagreement by climatologists on the subject. There is also no confident method to predict spontaneous future El Niño behavior in association with climate change. Therefore, the Intergovernmental Panel on Climate Change (IPCC), established by United Nations Environmental Programme (UNEP) constructed a climate model to determine the effects of increased greenhouse gases concentration on ENSO's behavior. The results of this model reflected that with the increase in global mean temperatures, the frequency of El Niño events and intensity of La Niña events will increase [15]. This proposition was further strengthened by the results of the Galapagos discovery, made in the later years, which suggested that the eastern region of the Pacific Ocean warmed from 900 to 1150 CE followed by a cooler period from 1150 to 1500 CE (also known as the Little Ice Age). It was only during the Little Ice Age that the ENSO activity became fairly frequent and volatile. This phase was then again followed by a period of less frequent and volatile ENSO activity. The results of this study were further used to understand the role of global mean temperatures in affecting ENSO events, their frequency and intensity [31].

ENSO and Natural Disasters: Though the highest numbers of people dead or affected by natural disasters are due to droughts and famines, the most frequent natural disasters are hurricanes and tropical windstorms, followed by floods. All of these are directly affected by El Niño events [15]. However, it is important to note that no individual disaster event can be solely attributed to El Niño, with absolute certainty; ENSO is one of the factors that boost the extremeness of these events. This section attempts to analyze El Niño regionally to understand its global impact. As a result of occurring in the Pacific Ocean, El Niño affects the Pacific Islands, Australia and South America the most. Due to the weakening and gradual reversal of Trade Winds, southwestern Pacific like Papua New Guinea and Cook Islands experience reduced rainfall, whereas central and eastern Pacific experience enhanced rainfall. Unlike the extremely wet and warm climate of South America, Australia experiences extremely cool and dry climate.

Also countries like Ecuador and Peru experience excess rainfall, i.e. almost 10 times the normal. On the other hand, southern and southeastern Asian countries are associated with droughts, due to extremely reduced rainfall [31]. Moreover, due to high absolute population and high population density, this expanse provides more than 50% of all disaster victims [15]. These drought conditions do not only take a toll on life directly, but also indirectly by increasing the risk of wildfires causing local as well as trans-boundary air pollution, which is a major health issue [27]. Even though El Niño occurs in the Pacific region, it affects global climates. Countries in southern and eastern Africa report below average rainfall leading to droughts and food insecurity [31]. As per NASA's report combination of high temperatures and drought increased the number and severity of wildfires in Southeast Asia, while drought stunted plant growth in the Amazon rainforest, reducing the amount of carbon it absorbed. A combination of warming temperatures and near-normal rainfall increased the rate at which forests exhaled CO_2 , in Africa during 2015-16 El Niño[32]. Kovats et al. observed that the number of people affected by natural disasters, during El Niño years, was relatively higher compared to other years [15].

ENSO and Biodiversity: The natural disasters that occur as a result of ENSO not only take a toll on human life, but also on biodiversity in general. The flora and fauna of that area drastically gets affected by any type of natural disaster leading to ecological imbalance. Without a functional healthy ecosystem the chances of a disease thriving is very high as these changes in the ecosystem are undesirable to many of its biotic components but can prove advantageous to the vectors. An inverse relationship established between biodiversity and incidence of vector-borne diseases, i.e. greater diversity among vertebrates which act as reservoirs of pathogens, results in dilution of the principal reservoir, shows reduced chances of human-vector interactions. However, this logic holds true only if the vector attains the pathogens from vertebrates, rather than through transovarial transmission (i.e. via eggs). In case of high vertebrate diversity, the probability of a vector coming in contact with a competent reservoir of pathogens is very low, making the prevalence and risk of the disease lower. This dilution effect is clearly represented in the case of Lyme disease. Herein, a diverse group of vertebrates has the potential to dilute the impact of the principal reservoir of the pathogen (*Borrelia burdgdorferi*), which in this case is the white-footed mouse (*Peromyscus leucopus*). This will consequently lead to the reduction of risk of the Lyme disease [20].

Correlation with Vector-borne Diseases: The environmental conditions created by the weather phenomena [16], prove to be extremely favorable for the vectors, like mosquitos, to grow and survive. The greater surface water availability during heavy monsoons, floods or rainstorms provides appropriate niche for the mosquitoes to breed in abundance, resulting in increased transmission of diseases [14]. Apart from availability of breeding sites, other climatic factors that affect the survival of vectors are the intensity of the weather events, tolerance limits of the vectors, food and water availability and temperature [10]. For instance, with respect to the intensity of weather events, during seasonal rainfall, the number of mosquitoes increases, due to the increased availability of breeding sites; however, during floods, caused by excess rainfall, the mosquito count may sometimes fall, due to the washing away of the breeding sites, by the floodwaters [2]. Food and water availability determines vectors' activity patterns, which involve feeding, host and mate seeking, etc. Other factors that determine the spread and intensity of vector-borne diseases are size and density of the host population, the socio-economic status of the affected human population, vector control programs for prevention and emergency response, genetic changes in pathogens and vectors (which determines their drug/pesticide resistant) [12].As discussed so far, it is clear that there is a strong correlation between ENSO and vector-borne diseases; however, this relationship has always been not so simple to study. This is because data on the vector population has been difficult to be collected over long periods of time. Therefore, in order to study the correlation between ENSO and vector-borne diseases, it is necessary to adopt a comprehensive evidence-based regional approach [15]. This is primarily because, under this study, different regions undergo various changes, therefore, making it almost impossible to generalize the results of one study, as that of the world's; furthermore, it is crucial to understand the exclusive conditions which makes ENSO's impact on one region different from the other, in order to have a better understanding on this subject matter. The recordings of the direct impact of ENSO events, like temperature and precipitation variances provide climatological evidence. The biological evidence is supported by the biological link between the vector and the weather events, that involve factors like, sea surface temperature, land surface temperature, precipitation, humidity, etc. which result from ENSO events. Statistical data on yearly basis of the number of people affected by vector-borne diseases, in order to associate it with the El Niño years validates the epidemiologic evidence. This should also involve data on the additional cofounding factors, which may affect vector abundance, since they would be closely linked to the ENSO events as well. Other important data, which if not collected and analyzed could lead to the generation of skewed results, involve affected population's vulnerability, dependent on the state's policy on vector control, prevention and treatment, along with the health infrastructure of the affected area. Lastly, it is also important to take into consideration, the periodic nature of a vector-borne epidemic, which could be highly dependent on the waxing and waning of herd immunity. In order to conduct a regional analysis, it is very important to collect geographical data, both at local and national level. This would involve, not only the vector ecology, host-parasite interaction and physical effects, scale and magnitude of ENSO events, but would also comprise a record of social changes, like availability of health infrastructure and services and the process of case detection [15].

Epidemiologic Evidences: The following section provides evidence of correlation of ENSO with three different vector-borne epidemics, Malaria, Dengue and Leishmaniasis. These examples indicate creation of favorable weather conditions, in terms of temperature, humidity and precipitation, required for survival and growth of vectors.

Historic Malarial Epidemics in Colombia: Malaria is the most widespread, vector-borne infection in the world [3]. According to WHO, 95 countries in 2015 had ongoing malaria transmission, posing as a risk to more than 3.2 billion people, almost half of the world's population. An estimated of 2.14 million cases of malaria, with around 438,000 deaths occurred worldwide in 2016 [24]. Apart from transmission through mosquitos, it can be transmitted through blood transfusion, organ transplant and shared use of syringes and needles contaminated with blood of infected individual or through transplacental transmission [19]. However, vector control is the primary prevention technique to hinder malaria transmission [29].
The understanding of Colombia's climate, in relation with ENSO is required to study the relationship between Malaria and ENSO. Colombian climate is extremely variable. Mean annual precipitation ranges from about 50-300 mm near the Caribbean coast to about 10000-13000 mm near the Pacific coast. The altitude of the mountainous region ranges from 0 to 5800 m, which accounts for the ambient temperatures to be influenced by the Trade Winds, absolute air humidity and the local air and pressure circulation system. The collision of the warm easterlies with the cool breeze from Pacific Ocean creates atmospheric instability; usually resulting in excessive precipitation in western and central Colombia [4].During El Niño years, the warm easterlies and the weakened Pacific Trade Winds together are responsible for the overall increase in air temperature in Colombia. It is interesting to see that instead of an expected rise in rainfall in Colombia (as a result of being on the western coast of South America), during El Niño, it experiences reduced rainfall, consecutively leading to negative anomalies in soil moisture and river discharges. This is due to the disruption of prior atmospheric instability (regionally specific to Colombia), which was the primary cause of excessive precipitation [21]. Apart from all these climatic changes, Colombia's topography further enhances the populations' vulnerability to Malaria. The malarial vectors in this country include *Anopheles albimanus*, *Anopheles darlingi* and *Anopheles nuñeztovari*, and they transmit *Plasmodium falciparum* (46.5%) and *Plasmodium vivax* (53.5%), with rare cases (8-10 per year) of *Plasmodium malaria* [21]. Transmission of Malaria is a seasonal phenomenon in the highlands (most prone to temperature variability), indicating temperature to be the primary controlling factor in the epidemiology of Malaria, related to ENSO, in Colombia [4]. El Niño weather changes in Colombia, not only prove favorable to the vectors, but also to the pathogens of Malaria, especially *Plasmodium vivax*.

Historic Dengue Epidemics in Thailand: According to the WHO, around 3.9 billion people from a total of 128 countries are at risk from Dengue. Recent statistics project an estimated 284-528 million Dengue infections per year, out of which 67-136 million are severe cases. Due to the commonality of this disease, with others, a lot of cases go unreported, making it extremely difficult to come to a fairly estimated statistical conclusion [25]. There was an upsurge of Dengue fever, during World War II, due to continuous migration of people from one place to other and high population density in cities, making it a hyper-epidemic. This resurgence of Dengue was primarily seen in South-east Asia and Latin America [13].

Dengue is caused by the Dengue virus of the genus *Flavivirus* and family *Flaviviridae*, which is transmitted primarily by female *Aedes aegypti* mosquitoes [9]. These vectors obtain the virus themselves, during feeding on an infected human host. They can further transmit this pathogen to the next generation of *Aedes* mosquitoes, through transovarial transmission, resulting in a greater population of infected *Aedes* mosquitoes, causing increased incidence of Dengue among humans [30]. Precaution from these vectors is the only form of prevention currently available, since even though, efforts are made towards the development of Dengue vaccines, no vaccine has been yet approved by the Food and Drug Administration of any nation [26].

Thailand receives an average annual rainfall of 1200-1600 mm every year, with its annual mean temperature not exceeding 40°C [7].Due to its geographical location, its climate is constantly under the influence of the seasonal southwest and northeast monsoon winds. The southwest monsoon winds bring in warm moist air from the Indian Ocean, causing tropical cyclones and abundant rainfall over the country, during May. As these winds move northwards, during June and July, upper and central Thailand experiences a dry spell. This is further enhanced, especially in the high altitude Northern and Northeastern parts of Thailand, with the blowing of cold and dry northeast monsoon winds; whereas, the eastern coast of Thailand experiences mild weather and abundant rainfall [7]. During El Niño, due to the weakening of the Pacific Trade Winds and their gradual reversal, Thailand as a whole, and the east coast of Thailand in specificity, experience extreme dryness, therefore, resulting in drought situations [23].

According to a study conducted from 1983 to 1997, the timings for increase in the Dengue cases and the timings of incidence of El Niño, did not always match. There is evidence for non-stationary association between the incidence of El Niño and Dengue epidemic in Thailand. A statistical analysis suggests that in most of the El Niño years, the increase in the number of Dengue cases precedes the incidence of El Niño in Bangkok [5], whereas, the occurrence of these two variables in the rest of Thailand is perfectly synchronized [11]. This shows that Dengue epidemics in rest of Thailand occurred three months later than the Dengue epidemic that broke out in Bangkok. However, in certain years, like 1983-85 and 1991-97, the incidence of Dengue in the rest of Thailand preceded the one in Bangkok by a period of one month [5].

It has also been found that there is significant coherence between the occurrence of Dengue epidemics and seasonal peak in rainfall, in the rest of Thailand, in comparison to that of Bangkok, wherein, the incidence of Dengue follows the seasonal peak in rainfall, after a short period of time. In most countries, Dengue is prevalent during the wet season; however, in countries with abundant rainfall (like Thailand), Dengue is more prevalent during droughts, since this causes the fast-flowing waters to slow down and form stagnant pools, which prove to be perfect breeding grounds for *Aedes* mosquitoes. This is also the primary reason for the seasonal peak in rainfall to precede Dengue, by a short lag of time, in Bangkok [5].Unlike the case of Malaria in Colombia (wherein, Colombia's climate influences Malaria's incidence by favoring its vectors as well as pathogens), Dengue's incidence here is the result of Thailand's climate favoring primarily its vectors. Also, incidence of Malaria in Colombia was a function of changes in temperature, caused by El Niño; whereas, the incidence of Dengue in Thailand is the function of changes in precipitation, caused by El Niño. It is these differences in the effects of El Niño on different places that validate the importance of regional analysis, in a study like this.

Emerging Cutaneous Leishmaniasis in Costa Rica: Leishmaniasis is one of the most emerging and resurging vector-borne protozoal diseases, second to Malaria, in terms of the number of people affected [6]. According to the WHO, there are three different kinds of Leishmaniasis, namely, visceral (extremely fatal if left untreated; highly endemic in the India and East Africa), cutaneous (most common form of Leishmaniasis; endemic to Middle East and Central Asia) and mucocutaneous (leads to partial or total destruction of mucous membranes; endemic to Bolivia, Brazil and Ethiopia) [28]. Leishmaniasis is primarily caused by protozoan *Leishmania,* transmitted to humans by the bites of an infected female *Phlebotominae* sandfly. There exists approximately 20 species of the pathogen and 90 species of sandfly which together cause and transmit this disease. The incidence of this disease could be caused by a variety of factors, like poor sanitation and waste management (increasing the sandfly breeding and resting grounds), crowded housing (providing the sandfly more blood-meals), poor diet lacking in protein, iron and vitamin A (increasing the risk of infection), deforestation, land degradation and climate change (leading to environmental changes for the growth and survival of vectors and parasites) [28]. It has a strong seasonal pattern, which varies year-to-year i.e. interannual variability, making it extremely sensitive to seasonal and climatic changes [6].Costa Rica is geographically situated on the ENSO belt making weather and climatic variations repeat every 3-4 years. This climatic variation coupled with climatic sensitivity of Leishmaniasis, results in it being an emerging and resurging disease in this area. On the analysis of monthly records for this disease in Costa Rica from 1991 to 2002, with reference to ENSO variables like sea-surface temperature and Multivariate ENSO Index, it was found that the incidence of Cutaneous Leishmaniasis rises and falls in three-year intervals that match the ENSO cycle. This indicates towards an extremely strong correlation between climate and transmission of this disease, as a result of not only vectors being sensitive to climatic variability but also the parasites' development with the hosts being extremely sensitive to high temperatures. Moreover, the density of reservoirs is also sensitive to climate. This non-linear modeling of such epidemics enables us to understand the manner in which the sandfly reacts to increased humidity and the parasite reacts to increased temperature [6].

Acknowledgment: We would like to thank FLAME University, Pune, India, for providing a platform to work in a motivated academic environment.

References:

1. Abrahams, Jonathan. "El Niño and Health: Update of Global Overview for 2016." World Health Organization, 2016. 1-34.
2. Ahern, Mike, et al. "Global Health Impacts of Floods: Epidemiological Evidence." John Hopkins Bloomberg School of Public Health Vol. 27 (2005): 36-46.
3. Bi, Peng and Kevin A. Parton. "El Niño Southern Oscillation and Vector-borne Diseases in Anhui, China." Vector-Borne and Zoonotic Diseases,July 2005, 5(2): 95-100.
4. Bouma, M. J., et al. "Predicting High-risk Years for Malaria in Columbia Using Parameters of El Niño Southern Oscillation." Tropical Medicine and International Health Vol. 2.No. 12 (1997): 1122-1127.
5. Cazelles, Bernard, et al. "Nonstationay Influence of El Niño on the Synchronous Dengue Epidemics in Thailand." PLOS Medicine (2005): 313-318.
6. Chaves, Luis Fernando and Mercedes Pascual. "Climate Cycles and Forecasts of Cutaneous Leishmaniasis, a Non-stationary Vector-borne Disease." PLOS Medicine (2006).
7. Climatological Group, Meteorological Development Bureau, Meteorological Department. The Climate of Thailand. 2015. 6 Novenber 2016 <https://www.tmd.go.th/en/archive/thailand_climate.pdf>.
8. Dash, Sushil Kumar."El Niño and Southern Oscillation (ENSO)." Climate Change: An Indian Perspective. Ed. Cambridge University Press India Pvt. Ltd. Ahmedabad: Center for Environment Education, 2007. 26-32.
9. Back,A.T. and Lundkvist,A 'Dengue Viruses. an overview Infect Ecol Epidemiol. 2013; 3: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3759171/
10. Gage, Kenneth L. "Climate Change and Vector-borne/Zoonotic Diseases." 2008. http://www.ncagr.gov/oep/oneMedicine/noms/2008/
11. Gagnon, Alexandre S., Andrew B.G. Bush and Karen E. Smoyer-Tomic. "Dengue Epidemics and the El Niño southern Oscillation." Climate Research Vol. 19.No. 35-43 (2001): 35-43.
12. Githeko, Andrew K., et al. "Climate Change and Vector-borne Diseases: A Regional Analysis." Bulletin of the World Health Organization: Environment and Health (2000): 1136-1147.
13. Gubler, Duane J. "Resurgent Vector-borne Diseases as a Global Health Problem." Emerging Infectious Diseases Vol. 4.No. 3 (1998): 442-450.
14. Hunter, P. R. "Climate Change and Water-borne and Vector-borne Diseases." Journal of Applied Microbiology (2003): 37-46.
15. Kovats, R Savi, Menno J. Bouma and Andy Haines. El Niño and Health. World Health Organization. Geneva: Sustainable Development and Healthy Environments, 1999. http://www.who.int/globalchange/publications/en/elnino.pdf
16. Maelzer, Derek, et al. "El Niño and Arboviral Disease Prediction." Environmental Health Perspectives Vol. 107.No. 10 (1999): 817-818.
17. May, Robert M."The Changing Planet: Hydrosphere.". The Britannica Guide to Climate Change. Encyclopedia Britannica Ltd., 2008. 264-272.
18. Merrill, R M. "Foundations of Epidemiology." Introduction to Epidemiology:2011 Seventh Edition. n.d. 2-17.
19. National Institute of Allergy and Infectious Diseases. Malaria. 4 November 2016 <https://www.niaid .nih.gov/diseases-conditions/malaria>.
20. Ostfeld, Richard S. and Felicia Keesing. "Biodiversity Series: The Function of Biodiversity in Ecology of Vector-borne Zoonotic Diseases." Canadian Journal of Zoology Vol. 78.No. 12 (2000): 2061-2078.
21. Poveda G, et al. Integrating knowledge and management regarding the climate–malaria linkages in Colombia, Curr Opin Environ Sustain (2011), doi:10.1016/j.cosust.2011.10.004
22. Roux, Jacqueline. What is El Niño, the event contributing to South Africa's current drought? 11 February 2016. African Climate Reality Project. 1 November 2016 <http://climatereality.co.za/what-is-el-nino/>.
23. Singhrattna, Nkrintra, et al. Interannual and Interdecadal Variability of Thailand Summer Monsoon Season. 1 June 2005. Americal Meteorological Society. 6 November 2016 <http://journals.ametsoc.org /doi/full/10.1175/JCLI3364.1>.
24. US Department of Health and Human Services, Centers for Disease Control and Prevention. Malaria. 1 November 2016. 4 November 2016 <https://www.cdc.gov/malaria/>.
25. World Health Organization. Dengue and Severe Dengue Factsheet. July 2016. 5 November 2016<http://www.who.int/mediacentre/factsheets/fs117/en/>.
26. World Health Organization. Dengue Control: The Human. 2016. 5 November 2016 <http://www.who.int /denguecontrol/human/en/>.

27. World Health Organization. El Nino Sourthern Oscillation (ENSO) and Health. 1 November 2015. 3 August 2017 <http://www.who.int/globalchange/publications/factsheets/el-nino-and-health/en/>.
28. World Health Organization. Leishmaniasis. April 2017. 1 August 2017 <http://www.who.int/mediacentre /factsheets/fs375/en/>.
29. World Health Organization. Malaria. April 2016. 4 November 2016 <http://www.who.int/mediacentre /factsheets/fs094/en/>.
30. World Health Organization. WHO Report on Global Surveillance of Epidemic-prone Infectious Diseases - Dengue and Dengue Haemorrhagic Fever. 2016. 5 November 2016 <http://www.who.int/csr/resources/ publications/dengue/CSR_ISR_2000_1/en/index2.html>.
31. Zolfagharifard, Ellie. Is El Niño linked to Global Warming? Cooler conditions during Little Ice Age caused an increase in extreme weather, says study. 3 December 2015. 1 November 2016 <http://www. dailymail.co.uk/sciencetech/article-3345158/Is-El-Ni-o-linked-global-warming-Cooler-conditions-Little-Ice-Age-caused-increase-extreme-weather-says-study.html>.
32. http://www.nature.com/news/massive-el-ni%C3%B10-sent-greenhouse-gas-emissions-soaring-1.22440.

***