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Ascertaining the link between dengue and climatic conditions

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I examine climate-change related factors affecting the incidence of dengue in the Philippines. Dengue is estimated to cost hundreds of millions of dollars in the Philippines and worldwide in terms of treatment, surveillance and control, lost income, and other indirect costs per year. The disease is a burden especially for the poor, who are less able to access funds for treatment and are more heavily affected by the loss in income due to illness.

Econometric results show that temperature, precipitation, and the incidence of La Niña contribute significantly to the cases of dengue in the Philippines, since these conditions enhance the breeding, growth, and development of *Aedes aegypti*, the dengue-carrying mosquito. Better household sanitation practices are also found to reduce dengue cases, indicating that investments to enhance the public's adoption of hygienic and other health practices lessen the transmission of the disease. Such results are consistent with the findings of studies regarding dengue in other parts of the world and contribute to the growing awareness about the health impacts of climate change. This study provides policy makers with additional guidance as climate change in the region becomes more pronounced.

JEL classification: Q54, I18
Keywords: dengue, climate change, environmental health

1. Introduction

Dengue fever (or just dengue) is one the most high-profile public health problems in Southeast Asia; it is considered among the fastest emerging pandemic-prone viral diseases in many parts of the planet. The illness is normally identified through its distinct symptoms: the rash and fever. It is not considered fatal, unless it develops into dengue hemorrhagic fever, which could lead to circulatory failure resulting in death, especially among children. The severity of the dengue fever ranges from mild to severe, depending on the age group and overall health of the patient. Other symptoms of the illness include muscle and joint pains, pain behind the eyes, and, in severe cases, febrile convulsions [World Health Organization 2001].

Dengue epidemics first became known to the world in the late 1700s when the disease was formally identified and named "breakbone fever" because of its symptoms. Individual cases consistent with dengue fever, however, were recorded as early as the Jin Dynasty (265-420 AD) when it was called insect-related "water poison." The origin of the name "dengue" itself is uncertain, but it is believed to derive from West-Indian-Spanish and Swahili words variously suggesting "cramped," "delicate," or "prudish," which possibly describe how people afflicted with the disease behave when they walk as a result of the pain in their bones.

Only at the turn of the 20th century was dengue's viral etiology understood. It was only in the 1950s, during the dengue epidemics in the Philippines and Thailand, when severe dengue was completely recognized. The disease is currently considered one of the leading causes of hospitalization and pediatric deaths in Asia and Latin America. It has spread to other regions in the world, including North America, Africa, the Caribbean and the Pacific; the disease affects an estimated 100-200 million people a year [Halasa et al. 2012]. Despite awareness regarding the disease and the advancement in modern health care and preventive medicine, dengue remains formidable in terms of incidence and economic impacts and it promises to remain so in years to come.

At the center of the dengue discussion is the vector (transmitter) of the disease: the female *Aedes aegypti* mosquito. Since there are four types of dengue viruses, complete immunity from dengue is possible if the patient is exposed to all four types. We must keep in mind, however, that sequential exposure to the four dengue viruses could lead to dengue hemorrhagic fever, which could result in death; as such, the possibility of being immune to dengue is, until recently, remote. A vaccine against dengue was piloted in the Philippines, but it has been plagued with questions regarding safety such that it remains to be a non-viable option at this time.

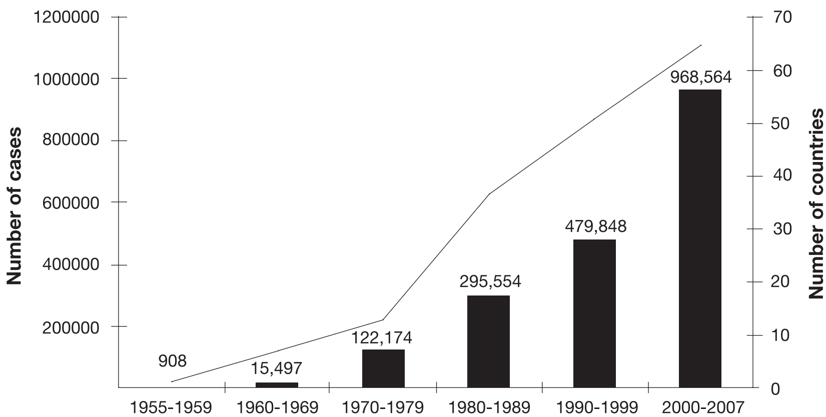
Until the anti-dengue vaccine is fully accepted and used, the most effective dengue prevention method is still the control and elimination of the dengue-carrying mosquito. There are several ways to accomplish this, but arguably the most aggressive entails the destruction of the breeding areas for the mosquitoes and fogging, or the use of insecticides to kill the mosquito population. Human behavior and living conditions also highly contribute to the potential for dengue infection, especially in the urban areas. Recently, there have been studies that indicate that environmental factors also positively impact dengue cases by encouraging the growth and breeding of the *A. aegypti* mosquito.

The scientific literature has identified common factors that impact the breeding of mosquitoes, such as temperature, rainfall, humidity, and the characteristics of water, e.g., salinity, pH, turbidity, and the like (The Open University [n.d.]; Kenawy et al. [2013]). One significant conclusion from the information on enabling factors contributing to the incidence of dengue is that these factors lead to the *A. aegypti* mosquito, the transmitter of the dengue virus and these factors are affected by climatic conditions. Weather patterns and climatic variables, such temperature and levels of precipitation, for instance, alter the physical characteristics of land and bodies of water, which in turn contribute to the changes in the population of dengue-causing mosquitoes. What is significant about these pieces of information is that they feed into the discussion regarding the global phenomenon that is characterized by long-term changes in these climatic conditions known as climate change. The warming of the planet—both from natural and induced factors—has been tagged as the force behind the general climate change, and with the international community recognizing that climate change is already happening, it is incumbent upon governments to act to blunt its potential effects. In this paper, one health effect of climate change in the context of the Philippines is given the spotlight to be recognized, as the links between climatic conditions and dengue cases are established resulting from global warming and climate change. This is an important consideration among policy makers when deciding on the direction of climate change adaptation and in crafting climate-resiliency strategies.

2. The social burden

The World Health Organization (WHO) reports that dengue cases increased 30-fold in the last five decades, causing millions of infections every year and costing economies billions of dollars in terms of lost productivity, treatment costs, and opportunity cost of public funds. In the Philippines, where dengue is endemic, there was an average number of 117,065 cases per year from 2008 to 2012. In total, there were 585,324 dengue cases during this period, according to the Department of Health, which placed the country in fourth place in terms of dengue burden in Southeast Asia. Edillo et al. [2015] estimate that clinically diagnosed dengue cases have direct medical costs of $345 million for the same period.

Because of dengue's regularity in incidence and the consistent magnitude cases, its economic costs have been tremendous, running hundreds of millions of dollars a year, based on estimates of individual country-specific studies. In Puerto Rico, for instance, Halasa et al. [2012] calculate that the average economic cost of dengue cases (adjusted to include non-reported cases) in the island was $38.7 million annually, excluding the cost of dengue surveillance and vector control. In other Latin American countries, the economic costs of officially recorded dengue cases are likewise large: $135.2 million for Brazil; $10.2 million for Venezuela; $1.7 million for El Salvador; $1.2 million for Guatemala; and $0.9 million for Panama [Suaya et al 2009, as discussed in Halasa et al.]. In the Philippines, the direct health cost (using both private and public health care) of an annual average 842,867 dengue cases is estimated to be $345 million (in 2012 prices) [Edillo, et al. 2015].



Source: Dengue Virus Net (http://www.denguevirusnet.com/history-of-dengue.html)

FIGURE 1. Cases of dengue in the world through time

The economic cost of dengue cases becomes even more important if we consider the issue of burden. Halasa et al.'s study, for instance, indicates that for Puerto Rico, the bulk of the cost of dengue falls on the household, followed by the government, and, lastly, the insurance firms. The share of the household becomes larger in ambulatory dengue cases, as opposed to a case with hospital confinement.. In the context of poverty, this situation is a cause for concern because poor households do not have the resources for treatment and mostly rely on the public health system; prevention, therefore, is the more logical approach to dengue management, rather than treatment. In this case, understanding the factors that contribute to dengue becomes imperative for the public and for government to do in order to undertake the necessary steps to reduce these factors.

3. Environmental, social, and behavioral underpinnings of dengue

The investigation regarding the relationship between climate change and dengue cases is not a new field of inquiry; the literature abounds with studies that explain the link between the two. For instance, Thomson [1938] and Watts et al. [1987] find through their laboratory experiments that the temperature and the level of humidity affect breeding patterns of mosquitoes. They conclude that these factors change the vector efficiency of dengue-carrying mosquitoes, and that higher temperatures shorten the incubation period of the dengue virus.

Similarly, Bangs et al. [2006] find a correlation between a severe decrease in rainfall and higher temperature and the incidence of dengue. Their findings, however, are not statistically conclusive; but the direction of relationship is established. More conclusive are the results of the study by Colón-Gonzalez et al.

[2013] in Mexico where they found a nonlinear relationship between dengue cases and temperature change. The study concluded that dengue cases are positively related to increases in temperature between 18 and 32 degrees centigrade, and that there is a statistically significant relationship between increases in precipitation (up to 550 mm in rainfall) and increases in dengue cases. The authors conclude that low to medium amounts of rainfall induce the collection of rainwater; and that high amounts of rainfall actually wash away the breeding sites, thus reducing dengue incidence.

It must be pointed out, however, that the literature indicates that incidence of dengue is affected not only by weather and climate factors, but also by a combination of variables related to behavior, information, urbanization, population growth, congestion, and human travel. While it is true that the probability of contracting dengue increases as environmental factors become more conducive for the breeding of the *A. aegypti* mosquito, human response to the threat of the illness blunts the sharpness of the possibility. For instance, government programs to educate the public regarding the threat of dengue and on how to minimize exposure to the dengue-carrying mosquito have proven to be effective in reducing dengue cases in the last few years. This is an important insight to keep in mind because it highlights the importance of the appropriate government intervention and human behavioral response in minimizing dengue cases, thus minimizing a potential addition to the economic burden of society.

The widely known information about dengue fever is that it spreads through the *A. aegypti* mosquito, its principal vector. Open and still water sources, both natural and artificial, serve as the medium in which this mosquito breeds and propagates. As a matter of strategy, dengue management and prevention have included informing the public about preventing water from accumulating in open locations (such as uncovered drums, cisterns, septic tanks, or exposed pipes), which could house mosquito eggs. This is paired with aggressive government and private sector campaigns to cover or eliminate open and still water sources and water treatment to kill mosquito eggs and larvae.

However, the dynamism of society and economic progress have made dengue management more challenging. For instance, greater access to piped-in water—a measure of growing urbanization—has aggravated dengue cases in Mexico because of the higher incidence of water storage within a dwelling place [Colón-Gonzalez et al. 2013]. Higher concentration of economic activities results in higher urban population density; this has significantly contributed to dengue cases because population density is positively correlated with the probability of spreading dengue [Gubler 1998]. The close proximity of people in population-dense areas, characterized by cramped living spaces, increases the probability of transmission of dengue between residents of a community.

4. Managing the number of dengue cases

The prevention of dengue cases entails two types of strategies, which, in turn, lead to different policy responses. The first strategy points to the management of the factors that increase the probability of infection, which directly means keeping the dengue-carrying mosquito population in check. Public health strategies along this line have focused mostly on information dissemination and fumigation and the direct control of potential breeding places.

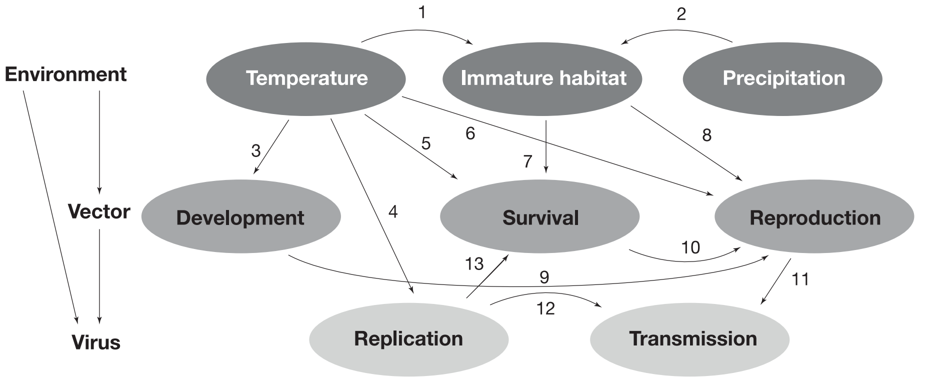
Control of the mosquito population, however, spills over to the second strategy of dengue management: the prevention of transmission. It is easy to discern that, holding other factors constant, an increase in the mosquito population increases the probability of infection and transmission.

The prevention of transmission is more of a behavior-modifying type of dengue management, which is better directed at inducing members of society to adopt specific practices that would reduce the probability of infection and transmission. This is where public funds as well as private initiatives are normally directed: educating sectors of society, especially those who are most susceptible to infection, on how to eliminate the possibility of contracting dengue.

5. The pathway of effect

In ascertaining the relationship between climate change and dengue cases, the path of the relationship must first be identified and explained. Climate conditions impact weather variables that are significant in enhancing the breeding of the carrier—the *A. aegypti* mosquito—and the ability of the human body to respond to exposure to the virus. As reported in Morin et al. [2013], Gubler et al. [2001], Rueda et al. [1990], Tun-Lin et al. [2000], and Watts et al. [1987] find that climatic conditions both directly and indirectly impact the population of the dengue-carrying mosquito by way of temperature and amount of precipitation. Temperature affects the mosquito's rate of development and behavior and the replication of the dengue virus within the body of the mosquito. In addition, temperature interacting with the appropriate amount of rainfall provides the breeding and habitat for the insect and affects the population of the dengue carrier. On the other hand, precipitation influences the availability of breeding and habitat areas for the insect [Morin, et al. 2013]. The studies by Troyo et al. [2009] and Van Benthem et al. [2005] also link land characteristics such as vegetative and tree cover to the number of dengue cases, while Chang et al. [1997] and Vanwambeke et al. [2005] point to land use as a contributor to the mosquito population which in turn heightens the probability of dengue infection. Other studies (Chang et al. [1997]; Vanwambeke et al. [2005]) also point to land use as a contributor to the mosquito population.

The chain of effects from climatic factors leading to dengue vectors is quite complex and difficult to describe in definitive terms, thus limiting the available information needed to determine what policy interventions can be established to effectively address dengue cases. According to Morin et al. [2013], "A climate variable may increase dengue transmission potential through one aspect of the system while simultaneously decreasing transmission potential through another." This indicates the difficulty in pinning down the net effect of a change in a climatic condition such as temperature. Still, the authors were able to map out a diagram that illustrates and summarizes the interaction of the factors that impact the transmission of dengue as shown in Figure 2.



Source for diagram and caption: Morin C. W., A. C. Comrie, and K. Ernst [2013] "Climate and dengue transmission: evidence and implications", *Environmental Health Perspectives* **121**(11-12): 1264-1272.

FIGURE 2. Diagram of biophysical influences on dengue vector ecology

This diagram shows the interactions between climate variables, vectors, and the virus. Numbers identify relationships between variables. Habitat availability for mosquito larvae is influenced by temperature through evaporation and transpiration (1) and incoming precipitation (2). Temperature is a major regulator of mosquito development (3), viral replication within infected mosquitoes (4), mosquito survival (5), and the reproductive behavior of mosquitoes (6). Habitat availability is required for immature mosquito survival (7) and reproduction of adult mosquitoes (8). Faster mosquito development and increased survival (9) will accelerate mosquito reproduction (10). Increased mosquito reproduction enhances the likelihood of transmission by increasing the number of blood feedings (11), whereas faster viral replication increases transmission by shortening the extrinsic incubation period (12). Last, increased survival of the adult mosquito increases the amount of viral replication (13).

From the information gathered, one can discern that although the interaction between the climatic factors and the conditions that result in a change in vector activity is complex, the stand-alone impacts of each can be ascertained. Still, more scientific inquiry is needed to bridge the gaps in the literature and to find out how the environmental conditions that are specific for each dengue-stricken country interact. For now, however, what can be done is to determine if there are links between different variables and the cases of dengue, such as this paper aims to achieve. In this study, the inquiry revolves around the fundamental question: How does a change in climatic condition influence dengue cases in a tropical country like the Philippines? In answering this question, it cannot be helped that the issue segues to the phenomenon of climate change and the need for nations to respond to it. The extent that the factors that cause climate change—both natural and man-induced—alters the known trend in climatic behavior is relevant to policy making because this information feeds into decisions regarding the design of strategies for adaption to climate change.

6. Methodology and data

Using Ordinary Least Squares with fixed effects, the 2004-2014 data collected from the Philippine Atmospheric Geophysical and Astronomical Services Administration, and the Department of Health per region were econometrically tested to determine possible causal relationships. Since the primary research inquiry of this paper focuses on climatic variables and their effect on dengue cases, the different variables mentioned in the literature were supposed to be included in the empirical model for this study, namely, temperature, humidity, and rainfall. These variables were supposed to be tested along with existing policy variables that represent government health programs, but the time and resource limitations did not allow for additional data collection that would have captured these variables.

The dummy variable for La Niña occurrence, however, was added to the model in order to determine if this weather deviation could exacerbate dengue cases. The inclusion of La Niña in the model was done upon reflection that this climatic phenomenon (where the sea surface water cools down below normal) affects the normal cycles of rainfall and dryness of the seasons in the world and could affect the development of the *A. aegypti* mosquito. It must be stressed that La Niña is considered a natural phenomenon, although there is an ongoing debate as to whether its severity and pattern of occurrence have been affected by global climate change. The link between climate change and La Niña is not explored in this paper, only the potential relationship between the presence of La Niña and cases of dengue in the Philippines.

In summary, the basic empirical model is specified as follows:

Frequency of Dengue = f (MTemp, RelHum, TotRain, LN, HealthExt,
San, HH)

where MTemp represents average temperature, RelHum is relative humidity, TotRain is total rainfall, HealthExt is the number of health stations in the area, San is proportion of households with proper sanitation, and LN is the dummy for years that the La Niña phenomenon was recorded. The variables MTemp, RelHum, TotRain, and LN were selected based on the scientific literature that identified these climatic conditions as key determinants of the development and breeding of the dengue virus-carrying mosquito.

The other variables, HealthExt and San, were selected to represent the government program health intervention and the communities' proactive actions to address health issues such as dengue. The presence of health stations represents the presence of health programs in the communities—presumably one of which would be dengue prevention—while the proportion of households with sanitary facilities represents a community's behavior toward proper sanitation that affects the breeding of the *A. aegypti* mosquitoes. It must be noted that the intent was to use dengue incidence as the dependent variable in order to adjust the model for variations in population, which would affect the number of dengue cases in each region. Unfortunately, there were gaps in regional population data that could not be bridged without affecting the results. As an alternative, the variable HH, the total number of households for each region, was added to the model to take into account the impact of population-related influence on dengue incidence.

Assembling the data used for the econometric testing proved challenging. The variable for dengue cases was directly generated from the Department of Health, while the climatic data were collected from the Philippine Atmospheric Geophysical and Astronomical Services Administration. The health department's published data on dengue had gaps, which forced the author to use the raw data from the department's office. The difference between the two sets was that the published data were already adjusted for underreporting. In order to keep all the data consistent, it was necessary for the raw data on dengue cases to be used. The rest of the data were sourced from the Family Income and Expenditure Survey. All data were time series, for each quarter for twenty years. The conduct of this study revealed the continuing difficulty in data collection in the country, which must be addressed for proper research to be done.

7. Results and analysis

Econometric testing was fairly straightforward, with three out of the four climatic variables registering significant statistical relationships with the dependent variable, regional dengue cases across time. It is also worth noting that the statistical significance of the data on number of households indicates that the model has appropriately included and taken account of the possible effect of population on the number of dengue cases. The results are summarized below, reflecting consistency with the scientific information in the literature linking dengue incidence with environmental and weather-related variables.

TABLE 1. Summary of econometric results

Dengue cases (Frequency of Dengue) = Dependent Variable	Coefficient	Robust Standard Error	T	P > |t|
Number of Households (HH)	0.00754	0.0016758	4.50	0.000
% of Households with Proper Sanitation (San)	337.3841	87.33511	3.86	0.000
Number of Health Stations (HealthExt)	4.089868	1.956504	2.09	0.042
Log San	-3570.131	1187.238	-3.01	0.004
Total Rainfall (TotRain)	1.787017	0.9718536	1.84	0.072
Mean Temperature (MTemp)	4575.233	2124.976	2.15	0.037
Relative Humidity (RelHum)	20.3736	231,1128	0.09	0.930
La Nina Dummy (LN)	3020.929	1086.897	2.78	0.008
Constant	-150040.1	69704.18	-2.15	0.037

The figures in Table 1 suggest that higher recorded precipitation—perhaps interacting with warmer temperature—does significantly contribute to dengue cases. From these results and the findings of other studies, we can conclude that the Philippines is the same as any case in other parts of the world; and that higher precipitation encourages the proliferation of outdoor breeding sources for the *A. aegypti* mosquito. Temperature increase also induces more cases of dengue; the higher ambient temperature shortens the development and incubation periods of the *A. aegypti* larvae, which in turn increases these insects' population growth rate. Higher temperature also increases the feeding rate of the *A. aegypti* mosquito, which means that the transmission rate of the dengue virus increases as well.

The results, however, fail to support the conclusion of other studies regarding the positive impact of humidity on dengue cases. As far as the Philippines is concerned, relative humidity is not a significant contributor in the breeding and development of the dengue mosquito, nor does relative humidity impact the vulnerability of the members of the communities to the dengue virus once they are bitten by the dengue mosquito. Further scientific inquiry is suggested to determine the true reason that humidity is not a factor in dengue cases, even if the literature suggests that it should be.

While there has only been speculation that the presence of La Niña has a direct effect on dengue cases, this study econometrically links the La Niña phenomenon with increases in dengue cases. The results indicate that there is a statistically significant increase in dengue cases during the years that La Niña occurred. La Niña is the worldwide weather phenomenon that is normally associated with unusual levels of average precipitation; and the results indicate that the continuous wetness induces the development and rise in population of the dengue mosquito.

Worth noting among the results is the statistically significant correlation between dengue cases and the non-climatic variables tested, specifically the proportion of households with proper sanitary facilities and the number of health stations in the community. According to the results, there is a negative relationship between the log of proportion of households with sanitary facilities and dengue cases, which is consistent with the WHO advice that proper disposal of solid waste impacts the growth of the population of the dengue-carrying mosquito: the higher the percentage of households that use proper sanitary facilities, the less the cases of dengue. This suggests that the positive behavioral response to health issues, such as investing and adopting hygienic practices, does have a significant impact on the control and management of transmittable illnesses such as dengue.

Regarding government health programs, the positive and statistically significant relationship between the number of health stations and dengue cases is both curious and counterintuitive. While the relationship is statistically significant, the results show that the direction of relationship between the number of health stations and dengue cases is positive: that more health stations are associated with more dengue cases. This is puzzling. This result could reflect the fact that additional health stations—for treatment and health counseling—may have been built in response to rising cases of dengue, but this conjecture needs to be validated with data, which are not available at the time of this writing. Also likely, however, is that the number of health stations as a variable in the model does not represent the government's level of investment to prevent a rise in dengue cases and that a more appropriate and better representative variable is called for. Unfortunately, more primary data—which might be primary in nature—would have to be collected and evaluated to replace the number of health stations in the model as the proxy for government initiatives to prevent dengue cases.

With a fairly high adjusted R^2 of 0.6, the model specified in this study does seem to explain the variability in regional dengue cases across time; and thus, the variables tested—especially the climate and weather-related variables—are then deemed significant contributors to dengue cases. Equally important to note is the result pointing to the public's degree of health awareness as also being key in managing total dengue cases in the Philippines.

8. Summary and conclusion

This study's main objective is to determine if climate-related factors induce increases in dengue cases in the Philippines. The economic cost of dengue is high with the economic burden being borne most by the poor who suffer lost income due to illness. As such, every bit of information that can be gathered in order to better manage the incidence of dengue is essential to reduce these costs. What this research sets out to do is not ground breaking; this type of analysis has been done in other countries. However, since there has been no known study that explored this question in the Philippine context, this study frames the problem and localizes it. This study's results are significant because they have formally verified if the climate-related variables that have been investigated in other countries are also relevant for the Philippine situation. The most significant contribution of this paper, however, is it provides additional proof that climate change—whether natural or hastened by humans—is a serious and multi-faceted problem which demands the public's attention. The results of this study could be a basis for policies concerning adaptation to the long-term impacts of global warming on the planet's climate especially on regional temperature, precipitation, and intensity of weather disturbances.

The scientific literature has provided the explanation for the causal link between temperature, humidity, precipitation, and dengue cases. The agent of the connection between climatic factors and cases of dengue is the *A. aegypti* mosquito, whose breeding and development are affected by environmental factors. Although the chain of effects that climatic factors trigger can be quite complex, the individual effects on specific stages of the *A. aegypti*'s larval development and breeding phase have been identified, *ceteris paribus*.

Temperature has been found to affect the behavior of the dengue-carrying mosquito as regards its breeding and the replication of the dengue virus inside the mosquito. Temperature, combined with the amount of rainfall, also provides the enabling condition for the habitat of mosquitoes. The result of this study that points to increases in temperature as a significant factor in inducing more dengue cases in the Philippines is consistent with the what the scientific literature says.

The amount of rainfall that accumulates has also been a significant contributor to the number of cases of dengue in the Philippines. As explained by the literature, more and prolonged rainfall episodes increase the possibility of accumulated and still water, which serves as the breeding ground for the *A. aegypti*. The scientific literature, however, also points to low, moderate, and prolonged rain—and not strong and heavy rainfall—as being positively associated with the growth in the population of the dengue-carrying mosquito. Rainfall associated with storms, for instance, will most likely destroy the breeding grounds and habitat of the *A. aegypti* because it is accompanied by strong winds.

Continuous rain without strong winds is associated with La Niña; the wetness and dampness that La Niña brings would be the reasons why the phenomenon is positively and significantly associated with dengue cases. It must be noted that although La Niña does happen naturally, its increasing frequency is attributed to general global warming. However, more scientific investigation needs to be conducted in order to ascertain if these two occurrences are causally related.

The results suggest that as more households become proactive in preventing dengue by way of better solid waste management, the higher the likelihood that dengue cases would decline because proper solid waste management lessens the breeding areas for the dengue virus-carrying mosquitoes. Solid waste management, after all, is essentially a function of households' participation in government sanitation programs.

The overall conclusion of this paper is that the factors that affect the incidence of dengue in the world are very similar to the factors that impact the severity of dengue in the Philippines. The study has ascertained as well that climatic conditions are significant contributors to dengue cases; it would be wise for policy makers to monitor changes in these conditions. This suggests that the Philippines must be vigilant in making sure that changes in climatic conditions are met with the appropriate policy and program responses in order to mitigate the health hazards they pose.

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