Review Research

IMPACT OF CLIMATE CHANGE ON ABUNDANCE, DISTRIBUTION, AND SURVIVAL OF AEDES SPECIES: SYSTEMATIC REVIEW

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ABSTRACT

Introduction: Aedes species is a common vector that causes various types of infection. One of the factors that can affect their distribution is the climate change. Identifying the components of climate change that can affect this distribution and how they affect it can aid in predicting and controlling the Aedes species distribution. **Methods:** Systematic search on articles related to the impact of climate change on Aedes species distribution was conducted using four databases namely Cochrane Library, PubMed, Ovid Medline and Science Direct. All the articles which were published within year 2014 till 2019, was then assesses by using the PRISMA checklist 2009 guided by the inclusion and exclusion criteria set. **Results:** Ultimately, 19 articles inclusive of six cross-sectional studies, six modelling and seven ecological studies were subjected to narrative and objective quality analysis using Newcastle-Ottawa Scale. Each component of climate change – rainfall, temperature, humidity and wind velocity were examined on its relational impact towards vector Aedes species distribution and survival. All studied climate components showed a unidirectional effect on the distribution and survival of Aedes species Temperature range 3.4ºC-34.2ºC, humidity <70%, post rainfall (<70mm) and low wind velocity related to increased vector Aedes species distribution, abundance and survival. Quality assessment yielded 17 high quality articles and two moderate quality. **Conclusion:** Climate change affects the Aedes species distribution and survival. By incorporating the knowledge on the effects of each component of climate change Aedes species vector control effort, a more objective and effective mitigation can be achieved.

Keywords: *Aedes species, climate change, impact, rainfall, Dengue, Aedes aegypti, Aedes Albopictus, vector abundance, vector survival, vector distribution*

Introduction

Aedes species is the vector for seven important communicable diseases that are causing a pandemic in humans and other reservoir hosts, including Dengue fever, Chikungunya, Zika virus, Yellow fever, West Nile fever, Ross River fever and Murray Valley Encephalitis (Cavrini et al., 2009; Walter Reed Biosystematics Unit, 2011). Aedes aegypti is a small to medium-sized mosquito of 4 to 7 millimetres (Yimer, Beyene, & Shewafera, 2016). The adult Aedes aegypti has white scales on the dorsal surface of that thorax resembled the shape of a violin or lyre while adult Aedes albopictus have one central white stripe at the top of the thorax. The abdomen of Aedes species is generally dark brown to black, some with white scales, the proboscis and the tip of the abdomen of the Aedes species come to a point, which is characteristic of all Aedes species (Carpenter & LaCasse, 1995; CDC, 2006; Cutwa & O'Meara, 2007). Generally, the females are larger than males, which can be distinguished by small palps of white or silver scales at tip. The female mosquitoes have sparse short hairs while mouthparts are modified for blood feeding; while male mosquitoes have plumose antennae and their mouthparts are modified for nectar feeding (Yimer et al., 2016).

The female Aedes aegypti feed almost exclusively on human blood only for the reason of ovi-production, other than that, the mosquito survived long with food other than blood (Zettel & Kaufman P., 2013). Feeding on humans generally occurs at one to two hours intervals, preferring to bite typically from below or behind, usually the feet and ankles (Yimer et al., 2016). The female Aedes aegypti are active biters, they are read to feed when the environment are favourable (Zettel & Kaufman P., 2013).

Aedes albopictus is an aggressive diurnal feeder feeding on a wider variety of hosts than the Aedes aegypti , they often present near human habitat, breeds well in artificial containers around the human habitat such as standing water bodies, coconut / durian shells, empty tins, opened water storage containers, as well as in natural containers such as leaf axils of water-holding plants like the bromeliads, or tree holes (Mu˜nnoz, Eritja, Alcaide, & al., 2011). The Aedes albopictus populations is capable to resist desiccation in temperate regions by produce diapausing eggs to curb the freezing cold winter season; and can feed on a wider diversity of vertebrate hosts by facilitating the establishment of enzootic arbovirus transmission cycles as a bridge vector in the America continent from spill-over of Dengue virus of sylvatic cycles in Asia (Motoki et al., 2019). With this, Aedes albopictus has a larger geographical distribution than Aedes aegypti (La Ruche, Dejour-Salamanca, & Debruyne, 2010). After taking a complete blood meal, female mosquitoes produce an average of 100 to 200 eggs per batch placed at varying distances above the water line, usually clutching at two or more sites (Yimer et al., 2016). The number of eggs produced is dependent upon the volume of blood meal feed. Females can produce up to five batches of eggs during a lifetime (Yimer et al., 2016).

The adult Aedes aegypti life span can range from two to four weeks depending on environmental conditions. Aedes aegypti comes in three polytypic forms: domestic, sylvan and per domestic. The domestic form breeds in urban habitat, often around or inside houses. The sylvan form is a more in rural form, breeds in tree holes and forests while the per domestic form thrives in environmentally modified areas such as coconut groves and farms (Maricopa County Environmental Services, 2006). The increasing vector-animal-human interaction has diverged the sylvatic cycle of transmission into the form of domestic, anthropophilic and phagic transmission forms (Powell & Tabachnick, 2013). Various natural habitat displacement and habitat creation by human activities, climate change and transmission tetrad (vector, agent, host, environment interaction) have successfully enlarged the distribution of Aedes species the region away from its originality (Shragai T, Tesla B, Murdock C, & LC., 2017).

Aedes aegypti and Aedes albopictus seem to have different susceptibilities to ZIKV, feeding rates, and feeding preferences, as Aedes aegypti feeds more often and almost exclusively on human as compared to Aedes albopictus which feeds on a broader range of hosts (Caminade C, McIntyre KM., & AE., 2017). Therefore, given equal mosquito and human densities, regions with Aedes aegypti will have a higher affinity for DENV, ZIKV, CHKV and YFV, but since Aedes albopictus extends beyond the range of Aedes aegypti into more temperate regions, it is more often found as the Aedes species which carry flavivirus transmission risk (Caminade C et al., 2017).

Extreme Weathers

More than 50% of the earth's climate change was a result of anthropogenic activities and is happening at a rate faster than the earth ecosystem can recover (Stocker et al., 2013). Intergovernmental Panel on Climate Change forecasts an increase in world average temperature by year 2100 within the range 1.4 ºC –5.8ºC since year 1995; and the global temperature is rising at the rate of 0.5ºC annually since year 1970 (McMichael, Woodruff, & Hales, 2006), more remarkably seen at higher latitudes areas. This leads to extreme weather events in a more frequent, severe and higher variable mode (Hainesa, Kovatsa, Campbell-Lendrumb, & Corvalanb, 2006; McMichael et al., 2006). The mortality rate related to extreme weather is well established and represented by the U-shape / J-shape curve, where median temperature (the thermo comfort zone) has the lowest death rate, and the mortality rate increases in exponential relationship with the rise of temperature, also to lesser extent, the fall to low temperature (Abdul Rahman, 2009; Hainesa et al., 2006; McMichael et al., 2006).

In a warming climate, extreme events like floods and droughts are likely to become more frequent. More frequent floods and droughts will affect water quality and availability. Increases in drought in some areas may increase the frequency of water shortages and lead to more restrictions on water usage. An overall increase in precipitation or rain may create greater flood potential. Rising sea levels, meanwhile, heighten flood dangers for coastal farms, and increase saltwater intrusion into coastal freshwater sources making those water sources too salty for irrigation or drink (Backlund, Janetos, & Schimel, 2008). Precipitation also can washes-off pesticide from the agricultural site and spread the pesticide to water sources such as underground water thus making it contaminated. Same as food supply, extreme climate can result in greater water source spoilage and disrupt water distribution, water storage, transport and dissemination.

Climate Change in Relation to Vector Distribution

Flood / rain fall related vector borne diseases like dengue fever, malaria, leptospirosis, Chikungunya endemics are more prevalent in the country and worldwide; through the development of more breeding sites, contamination of surface run-off and poor hygiene practice during the disaster. Urbanization brings forth more complex human-vector interaction epidemiologically and ecologically, account for the worsen endemicity (World Health Organization & United Nations Environment Programme, 2007). The illegal logging activities may result in malaria virus transmission via rural-urban vector-human interaction (World Health Organization & United Nations Environment Programme, 2007).

Mosquito Aedes species usually live between the latitudes of 35°N and 35°S below an elevation of 1000m at both natural and artificial terrestrial and aquatic habitats (NC. Dom, Abu, & Rodziah, 2013). Climatic factors are strong environmental drivers for arbovirus disease transmission, this is particularly true for factors such as environmental temperature, relative humidity and rainfall patterns (Rodo, Pascual, & Doblas-Reyes, 2013). The risk of viral transmission from Aedes species is highly sensitive to climate. Temperature impacts the ectoderm's internal body temperature, hence directly affecting the mosquito physiology (e.g., immunity) (Murdock, Blanford, & Luckhart, 2014), the mosquito development, survival, reproduction, biting rates (Ciota, Matacchiero, & Kilpatrick, 2014), vector competence and extrinsic incubation periods) (Ciota et al., 2014). In hot and dry climates, Aedes albopictus eggs may be more susceptible to desiccation, thus becoming less competitive to Aedes aegypti (Shragai T et al., 2017). This capacity of vector-borne disease transmission and affinity of transmission are influenced by the mean number of blood meals in a typical mosquito's remaining lifespan after mosquitoes were infected (Shragai T et al., 2017).

Urbanization further changes the natural habitat of both mosquitoes and of human, as well as climate suitable for the vector survival and transmission (Pincebourde, Murdock, & Vickers, 2016). Temperature, humidity, and the number of breeding sites in the city appeared heterogenous, vary depending on the economic status of the landowner or resident, mosquito control, zoning, and cultural norms. Micro environmental niche in the urban that turn out to be the mosquitoes hotspots are usually congested area with high population density, limited space, poor hygiene, sanitation and suboptimal sewage management; and these niches are often inhabited by human population with higher vulnerability to infection due to low socioeconomic and low sociodemographic status (Shragai T et al., 2017).

Modelling and Prediction of Vector Survival

Environmental niche modelling is usually used to predict suitability for disease transmission for Aedes Species. Modelling uses disease prevalence report against hypothesized environmental covariates to derive future potential of vector distribution (Messina et al., 2016). For example, modelling results indicate that temperature conditions related to the 2015 El Niño climate phenomenon were exceptionally conducive for Aedes species mosquito-borne transmission of ZIKV over South America (Caminade C et al., 2017). Regions with model prediction of high ZIKV transmission risk has high correlation with the subsequent large outbreaks occurring in Brazil, Colombia and Venezuela in year 2015–2016. This optimum thermal zones show largest simulated biting rates and lowest mosquito mortality rates and the shortest extrinsic incubation period in year 2015 (Caminade C et al., 2017). The sub-Saharan Africa regions demonstrated continuous suitability for ZIKV survival since the 1950s (Messina et al., 2016).

Nevertheless, the interpretation of relationships between mosquito abundance and land-use patterns is not as straight forward. The variation occurs due to different categorizations of landscapes used, such as the percent of vegetative coverage, human population density, outdated geographical map, map resolution. The inaccuracy is complicated by inappropriate scales used to quantifying these patterns. When large regions are used, the over broad geography may not appropriately representing the microclimate and available habitats within the regions, obscuring pattern of transmission (Shragai T et al., 2017).

With climate change being recognized fast as a determinant of health, this has become utmost important to estimate the effect of weather on vector borne diseases (Roy, Gupta, Chopra, Meena, & Aggarwal, 2018). Even though various control measures have been done, vector borne cases are still persistent which is likely due to the changing climate that is not factored to our control measures. There is no recent review done on the effect of climate change on Aedes species distribution globally. Being able to anticipate vector abundance in relation to the changing climate, a better vector control can be implemented. The review aims to understand how each component of climate change impacts the distribution and survival of vector Aedes species.

Methods

Literature Search

Systematic search related to relevant articles from four major search engines using Boolean search strategy, search engines including Cochrane library, PubMed and Ovid Medline and Science Direct, retrieving all articles published from year 2014 until 2019. PRISMA checklist 2009 is used to describe the workflow of articles search for this study (Page MJ et al., 2021). The keywords used to search for the articles are stated in Table 1.

Table 1: Initial keyword search using P.I.C.O. strategy

Keyword	Concepts	Alternative
Patient / problem	Aedes sp	Aedes sp OR Dengue cases OR Dengue Haemorrh#gic Fever cases OR Chikungunya cases OR Yellow fever case OR Zika case OR Flavivirus case
Intervention	-	-
Comparison	Climate change in SEA	Current Rain fall OR Current temperature OR current wind direction
Outcome	Vector distribution Vector survival	Vector distribution OR Aedes sp new case OR Pattern of Aedes sp. Distribution OR Vector Aedes sp. Evolution OR Vector life cycle OR Vector transmission OR Vector survival

Boolean Strategy Keyword search:
As the keyword combination did not yield sufficient search result after two rounds of Boolean Strategy Keyword search, contraction using a set of new keywords was done.

Aedes sp OR Dengue cases OR Dengue Haemorrh#gic Fever cases
AND
Rain fall OR temperature OR wind direction
AND
distribution OR new case OR Pattern OR Evolution OR transmission OR survival

Inclusion criteria for the article search including: (1) full text, primary research articles on prevalence of vector-borne diseases in relation to climate change (2) reported at least one outcome of the vector distribution due to climate change (3) articles published from year 2014 – 2019. Exclusion criteria set were: (1) reviewed articles of no original research work empirical data (2) entomology with no association to climate change (3) Knowledge, Attitude, Practice studies (4) clinical treatment (5) pharmaceutical study (6) vector distribution other than Aedes species

The articles obtained from the keyword search were first screened by titles to exclude totally irrelevant articles, then abstracts of the articles to look for P.I.C.O. criteria. When full texts are retrieved, it was assessed for relevance to include our inclusion and exclusion criteria. In total, there is a total of 440 articles retrieved based on Boolean search strategy, 36 accepted by title and further subjected for abstract screening yielding 31 articles. After excluding one duplicate article and eight that did not fit the inclusion criteria, a total of 22 articles were subjected for full text review. In the review, three more articles were excluded due to irrelevant content. The final full article reviewed and proceeded for analysis was 19. The progress of screening and selection is described through the Prisma flow chart in **Error! Reference source not found.**.

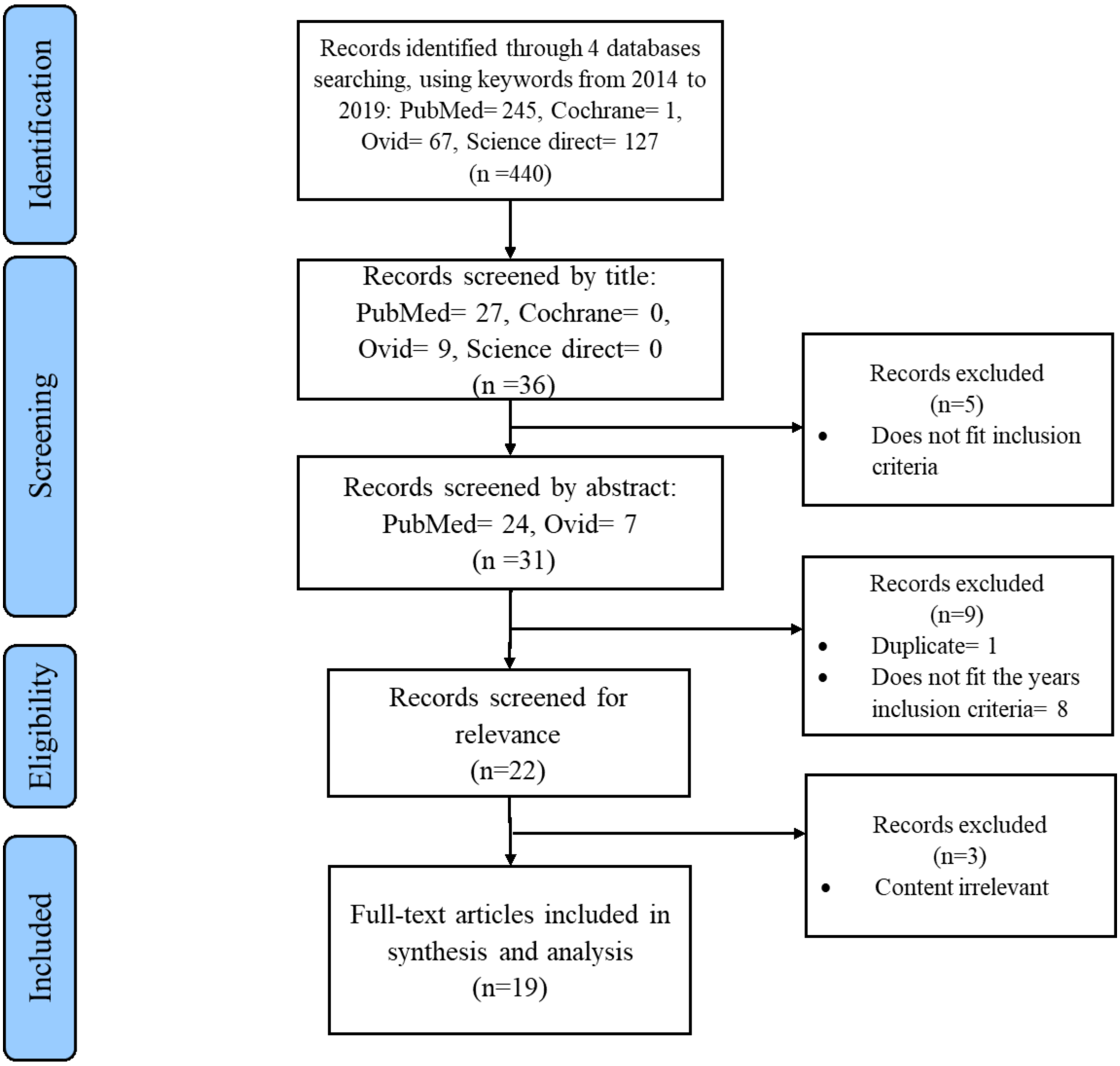

Figure 1: Prisma flow chart

Results & Discussion

Characteristic of study

A total of 19 articles which consist of six cross-sectional, six modelling and seven ecological studies were finalized for full text analysis. The articles are mostly from Europe and Asia. Amongst which 17 articles studied on temperature in relation concerning vector survival, eight on rainfall, eight on humidity, two on seasonality change and one on wind velocity. Table 2 provides a narrative review on the study design, tools, variables used, outcome of vector and challenge / limitation / public health implications. Total of 11 studies using ovitrap for mosquitoes sampling, the other eight uses secondary data from meteorology data, environmental survey or geographical intelligence systems. Table 3 provide the narrative analysis summary of various climate components effect on vector Aedes species distribution and survival. Nine studies reported on rainfall, where 55.5% (n=5) studies shows inverse relationship of rainfall with Aedes sp abundance, with each 1mm increase of rainfall contribute to 1% increase in vector abundance, up to 70mm. Nine studies were done on humidity, 66.7% (n=6) studies reported increased humidity will lead to increase in Aedes sp vector abundance, (Betanzos-Reyes, Rodríguez, Romero-Martínez, Sesma-Medrano, & Rangel-Flores, 2018) specified that humidity range 30-70% is suitable for vector survival, and consistently supported by (Da Cruz Ferreira et al., 2017) that humidity beyond 70% leads to reduction of vector survival. Seventeen studies studied effect of temperature with Aedes sp abundance and survival, 94.1% (n=16) supported that increase temperature proportionate to the increase of vector abundance, but (Limper et al., 2016) provided contrast opinion. The lowest temperature recorded for vector increment was 3.4ºC (Taber, Hutchinson, & Smithwick, 2017), and temperature maximum for increased vector was 34.3ºC by (Das et al., 2014). Review supported the J-shape relationship between temperature and vector abundance and survival, (Phung, Talukder, Rahman, Shannon, & Cordia, 2016) reported with every 1˚C increment, there will be an additional 11% risk to get Dengue infection (proxy to vector survival). Only three studies reviewed on wind velocity in relation to Aedes sp survival, all studies show inverse relationship.

Table 2: Narrative Review of Characteristics of Studied Articles

NO	Author/ Year	Country	Study Design	Tool	Variables	Outcome	Challenge / Limitation / Public Health Implication
1	Barrera et al. 2019 (Barrera, Amador, Acevedo, Beltran, & Munoz, 2019)	Puerto Rico (US Territory)	Comparative cross sectional (2014/2016)	Mosquito collection	Mosquito density Rainfall Temperature Relative humidity	Accumulated rain significantly influenced mosquitoes density (reduced during rain fall and increase post rain)	- Comparing the results with a previous study may not be comparable as the number of samples, sampling tools, techniques and analysis may differ.
2	Roy et al. 2018 (Roy et al., 2018)	India	Cross sectional study	Secondary data	Laboratory confirmed cases Rainfall Temperature Relative humidity	1. Relative humidity was associated with burden of positive dengue cases 2. Dengue admission was preceded by heavy rain 4–6 weeks earlier	-limited number of paediatric cases
3	Xiang et al. 2017 (Limper	China	Modelling	Dengue notification system data	Clinical and laboratory confirmed cases Rainfall	1. Positive temperature -Dengue associations were	- Non-climatic data was not accounte

	et al., 2016)			Meteorological data	Temperature Relative humidity Sunshine duration Wind velocity	found for both T_{max} and T_{min} at the range of 21.6–32.9°C and 11.2–23.7°C 2. Relative humidity was positively associated with dengue; however, a negative association was observed during extremely humidity. 3. Extreme rainfall and high wind velocity are associated with reduced cases.	d for in this model as data was not available
4	Phung et al. 2016 (Phung et al., 2016)	Vietnam	Modelling	Secondary data	Dengue cases Rainfall Temperature Relative humidity	1. A 1℃ increase in temperature increased the Dengue risk 11% (95%CI, 9-13) at 1-4 weeks and 7% (95%CI, 6-8) at 5-8weeks. 2. A 1% rise in humidity increased Dengue risk 0.9% (95%CI, 0.2-1.4) at lag 1-4 and 0.8% (95%CI, 0.2-1.4) at	- Uses mean value of climate factors rather than minimum, maximum or diurnal.

						lag 5-8 weeks 3. A 1 mm increase in rainfall increased Dengue risk 0.1 % (95%CI, 0.05-0.16) at lag 1-4 and 0.11% (95%CI, 0.07-0.16) at lag 5-8 weeks	
5	Limper et al. 2016 (Dhimal, Gautam, Joshi, O'hara, & Ahrens, 2015.)	Netherlands	Modelling	Distributed lag non-linear model Secondary data	Dengue cases, Rainfall, Temperature, Relative humidity, Sunshine duration	lower temperatures lead to higher rates of infection	-data for Dengue cases is obtained by month unlike climate changes by week.
6	Williams et al. 2015 (Williams et al., 2015)	Malaysia	Modelling	mechanistic entomology and disease model – secondary data	Dengue cases Daily temperature	Increase in temperature resulted in an overall decrease in Dengue activity	Model unable to predict future number of Dengue cases
7	IM Nurin-Zulkifli et al. 2015 (IM Nurin-Zulkifli. et al., 2015)	Malaysia	Cross sectional study	Mosquito collection HLC – human landing catch	Mean number of Ae. *albopictus* mosquitoes and meteorological parameters	-mosquito population correlated significantly with humidity & temperature -no significant correlation of mosquito species with Temperature and humidity	-
8	Taber E.D et. al. 2016 (Ciota et al., 2014)	Pennsylvania, USA	Modelling	geographic information systems (GIS) over 10 years	risk of Dengue virus transmission using a model that captures the probability of	*-Ae. albopictus* population density -monthly pattern of population increase correlate with	BG Sentinel traps was not used during earlier part of the study, given lower yield of *Ae.*

					transmission	temperature 3.4-32.7ºC -winter temperatures limit Aedes sp. egg survival	*Albopictus* catch evaluation of temperate *Ae. albopictus* populations helps in development of better biological models of DENV transmission.
9	Dutto M. & Mosca A. 2017 (Dutto & Mosca, 2017)	Northwestern Italy	Cross sectional study	Environmental risk assessment - interview, larvae sampling	Indoor mosquito breeding sites -for *Ae albopictus* only	Low external temperature (winter, 2-6ºC) restricted vector survival, encourage indoor vector survival	Insufficient survey sites to define real entity of winter presence of *Aedes* species in the area and the associated risk of vector-transmitted diseases
10	Rodrigues et. al. 2015 (Grech et al., 2019)	Brazil	Cross sectional study	Mosquito collection - Portable electrical catcher	Female *Aedes aegypti* & *Ae. Albopictus* over number of residents for intradomiciliary and peridomiciliary premises	strong association between no. of female adult mosquitoes and the number of residents in both intradomiciliary and peridomiciliary premises 77% (p = 0.000) female adult Aedes sp intradomiciliary premises and and 48% female adult *Aedes sp* peridomiciliary premises due to mean	high probability of human-vector contact can increase possible transmission and spread of the DEN virus. Part of the *Aedes sp* mosquito behaviour is the adaptability to vast differentiated environments

						rainfall (p=0.001) Min temperature in both types of premises contributes to 40% of no. of female mosquitoes	Entomological indicators of adult females should be use for vector control
11	Marta R.H.S et. al. 2018 (Marta, 2018)	Brazil	Cross sectional study	Mosquito collection using ovitrap	- rainfall and temperature - oviposition rates	seasonal variation (min, max temperatures significantly associated with oviposition rate of both *Aedes sp.* Cumulative rainfall (weekly) not associated with vector abundance	*Ae. aegypti*, closely associated with inhabited region (more human); *Ae. albopictus* was more closely associated with area with a greater vegetation coverage
12	Sadie J.R. et. al. 2019 (Sadie J. R., Colin J. C., Erin, & Leah, 2019)	USA		Modelling - general circulation models – secondary data	Temperature	mosquito range shifts track optimal temperature ranges for transmission (21.3–34.0˚C for *Ae. aegypti;* 19.9–29.4˚C for *Ae. albopictus -poleward shift pattern observed* - significant reductions in climate suitability at southeast Asia and west Africa are expected for *Ae. albopictus*	climate change will lead to increased net and new exposures to *Aedes*-borne viruses both *Aedes* species vary in transmission rate under climate change, *Ae. Aegypti* endures wider range of climate change, but intermediate climate changes

							make *Ae. albopictus* a more suitable survival and successful competitor
13	Dhimal et al. 2014 (Dhimal, Gautam, Kreß, & Müller, 2014)	Nepal	Ecological study	Entomological survey: Adult mosquito collection by using BG-Sentinel and CDC light traps	Number of mosquitoes per trap and meteorological parameters	Temperature, rainfall and relative humidity had significant effects on the mean number of A. aegypti per BG-Sentinel trap:- • Each degree rise in temp increased female A. aegypti abundance (ß = 1.63; 95% CI = 1.34–1.98; p,0.001) • Every increased in rainfall (mm) reduced abundance (ß = 0.94; 95%CI =0.92–0.97; p,0.001) • Every increased humidity (%) also reduced abundance (ß= 0.59; 95%CI=0.44–0.77; p,0.001). No significant effect of rainfall and temperature	*Ae. aegypti* and *Ae. albopictus* established stable populations up to the Middle Mountains of Nepal, but not in the High Mountain localities. *Ae. aegypti* and *Ae. albopictus* trapped even when minimum temperatures had dropped to 8ºC suggesting a considerable adaptive capacity of local *Ae. aegypti* and *Ae. albopictus* populations to low temperatures → for better planning and scaling-up of mosquito-borne disease control programmes in the mountainous areas of Nepal that had

						on the number of *Aedes* eggs per ovitrap (p.0.05). Humidity had significantly negative effects on the mean number of *Aedes* eggs per ovitrap (b = 0.83; 95%CI = 0.71–0.97; p,0.001).	previously been considered risk free Increase temp shorten the extrinsic incubation period of pathogens, lead to increases in biting frequency and extensions of the average life span of mosquitoes ➔ Increasing temp can make temperate regions of Nepal vulnerable to DF epidemic
14	Da Rocha Taranto et al. 2015 (M. F. Da Rocha Taranto et al., 2015)	Brazil	Ecological study	Mosquito egg collection by using ovitrap	Average monthly temperature and precipitation was compared with the number of eggs collected in each month	The presence of the vector was significantly influenced by temperature variation (P < 0.05) Rainfall provided physical and climatic conditions favourable to the development of eggs and to the increased survival of the mosquito. However,	The higher temperatures provided better conditions for mosquito breeding, thus greater probability of transmitting DENV

						extreme rainfall conditions are not associated with vector presence over time, as the pattern may result from the elimination of larvae from overflowing containers.	
15	Betanzos-Reyes et al. 2018 (IM Nurin-Zulkifli. et al., 2015)	Mexico	Ecological study	Mosquito egg collection by using ovitraps	Correlation between climate variables eg. weekly report of temperature (average, minimum and maximum), rainfall (mm accumulated) and relative humidity (RH, percentage) and ovitraps data	Daily mean temperature, relative humidity and rainfall parameters were associated with mosquito egg abundance: Significant correlation was seen between the weekly *Aedes* egg counts with: The mean weekly egg counts (WEC): - increased with 12ºC to 18ºC, but decreased as temperature increased beyond this point. - similar at RH between 30 and 70% and increased as humidity increased beyond 70% - increased as rainfall increased up to 70mm, but unchanged with further	Time lags between egg counts and dengue incidence could be useful for prevention and control interventions. This time lag represents an opportunity to use ovitrap monitoring as a predictive tool for Dengue fever incidence incre-ments.

						increases in rainfall	
16	Da Cruz Ferreira et al. 2017 (Da Cruz Ferreira et al., 2017)	Brazil	Ecological study	MI-Dengue system (intelligent dengue monitoring, or MosquiTRAPs)	Daily rainfall, temperature parameters (minimum, average and maximum), and average relative humidity -Dengue incidence	Adult mosquito abundance was strongly seasonal, with low infestation indices during the winters and high infestation during the summers. Weekly minimum temperatures above 18 °C were strongly associated with increased mosquito abundance, whereas humidity above 75% had a negative effect on abundance.	Continuous monitoring of dengue vector population allows for more reliable predictions of infestation indices. The adult mosquito infestation index was a good predictor of dengue occurrence. Weekly adult Dengue vector monitoring is a helpful dengue control strategy especially in subtropical areas
17	Bezerra et al. 2016 (Bezerra et al., 2016)	Brazil	Ecological study	Adult female *Aedes albopictus* (and other *Aedes sp.*) were caught using BG-Sentinel Full Version®traps	-rainfall, temperature (minimum, maximum and average) and relative humidity -The field-caught *Ae. albopictus* collected females - The field-caught DENV-infected *Ae. albopictus*	1. Minimum temp of 12.1-23.2DegC (r=0.34, p< 0.0001 and maximum temp of 18.6-34.2ºC (r=0.25, p= 0.004) were correlated with the field-caught *Ae. albopictus* (n=511) in four different periods and districts. Neither the rainfall nor relative humidity was associated	Inverse association between the number of human Dengue cases and field-caught DENV-infected *Ae. albopictus* → in Brazil, possible that *Ae. albopictus* would be a less efficient DENV vector

						with the field-caught *Ae. albopictus* collected females 2. None of the climate variables were correlated with the field-caught DENV-infected *Ae. albopictus* (n = 79) in four different periods and districts	
18	Dhimal et al. 2015 (Dhimal et al., 2015.)	Nepal	Ecological study	Entomological survey: Collecting *Aedes spp*. Larvae	-daily rainfall, temperature and relative humidity	Significant effects of climatic variables on the mean abundance of each mosquito species: 1. *Aedes aegypti*: - Each degree rise in mean temperature increased Ae. aegypti abundance (β = 1.23; 95% CI = 1.18–1.29; P< 0.001) - Increased rainfall reduced abundance (β = 0.99; 95%CI = 0.99–0.99; P<0.001) - Increased relative humidity reduced the vector abundance (β = 0.91; 95% CI = 0.85–0.98; P<0.05).	Abundance of DENV vectors with mean temperature ranging from 10–25°C: shorten the extrinsic incubation period of pathogens, lead to increases in biting frequency and extensions of the average life span of mosquitoes

						2. *Aedes albopictus*: - An increase of mean temperature had a positive effect (β = 1.12; 95% CI = 1.06–1.20; P<0.05), - Total rainfall had a significant negative effect (β = 0.99; 95% CI = 0.99–0.99, P<0.001) - Relative humidity had a significant positive effect (β = 1.21; 95% CI = 1.08–1.35, P<0.001)	
19	Das et al. 2014 (Das et al., 2014)	India	Ecological study	Ovitrap surveillance	Larvae density per trap Data on max. temperature (T_{max}), min. temperature (T_{min}), morning relative humidity (0830 h), evening relative humidity (1730 h, total rainfall	1. Positive and significant correlations to vector density: - Maximum temperature (r = 0.45; *P* = 0.01) - Mean temperature (r = 0.408; *P* = 0.021) - Minimum temperature (r = 0.381; *P* = 0.032).	The relationships established between the weather parameters and the abundance of dengue vectors in the study areas could provide valuable inputs for the development of a decision support system for dengue esp. in Northeastern India. However, disease outbreaks also

							depend on factors such as the source of infection, susceptible human population apart from vector density and climate

All the climate factors were associated with at least one outcome of vector distribution or vector survival. **Error! Reference source not found.**3 analysed on the summative effect of each climate components to the vector survival / distribution. Objective analysis of quality of the studies was assessed using Newcastle-Ottawa Scale, with score range from 6 to 9 as described in Table 4. Total of 16 articles were rated as of good quality, two others with moderate quality of evidence from the objective quality assessment.

Table 3: Summarised Effects of Climate Components on Vector Distribution / Survival

NO.	STUDY	RAIN	HUMIDITY	TEMPERATURE	WIND VELOCITY
1.	Barrera et al. 2019 (Barrera et al., 2019)	- ↓ abundance of *Aedes sp*. during rain - ↑ abundance of Aedes sp. after rain	-	-	-
2.	Roy et al. 2018 (Rodrigues et al., 2015)	-	- ↑ humidity ↑ Dengue cases	-	-
3.	Xiang et al. 2017 (Oliveira Custódio et al., 2019)	- ↓ Dengue cases during extreme rainfall	- ↑ humidity ↑ dengue cases - extreme humidity ↓ Dengue cases	↑ Dengue cases during: - T_{max}: 21.6˚C-32.9˚C - T_{min}: 11.2˚C -23.7˚C	- extreme wind velocity will ↓ Dengue cases
4.	Phung et al. 2016 (Taber et al., 2017)	- ↑ 1mm rain ↑ 0.1% Dengue cases	- 1% ↑ humidity will ↑ 0.9% risk to get Dengue	- 1˚C ↑ in temp. will ↑ 11% risk to get Dengue	-
5.	Limper et al. 2016 (Rodo et al., 2013)	-	-	- ↓ temp. will ↑ Dengue cases	-
6.	Williams et al. 2015 (Williams et al., 2015)	-	-	- ↑ temp. will ↑ Dengue cases	-

7.	IM Nurin-Zulkifli et al. 2015 (IM Nurin-Zulkifli. et al., 2015)	-	- ↑ humidity ↑ Dengue cases	- ↑ temp. ↑ Dengue cases	-
8.	Taber E.D et. al. 2016 (Liu-Helmersson, Stenlund, & Wilder-Smith, 2014)	-	-	- Optimal temp. between 3.4˚C-32.7˚C will ↑ *Aedes sp.* - Winter temp. limit egg survival	-
9.	Dutto M. & Mosca A. 2017 (Dutto & Mosca, 2017)	-	-	- ↓ temp. during winter (2˚C-6˚C) will ↓ *Aedes sp.* survival outdoor, and ↑ *Aedes sp.* indoor	-
10.	Rodrigues et. al. 2015 (Xiang et al., 2017)	- ↑ rainfall will ↓*Aedes sp.* density	-	- ↓ temp. will ↓ *Aedes sp.*	-
11.	Marta R.H.S. et. al. 2018 (Marta, 2018)	-	-	- 1˚C ↑ in min. temp. will ↑ 8% abundance of *Aedes sp.* - 1˚C ↑ in max. temp. will ↑ 7% abundance of Aedes sp.	- For *Ae. albopictus*, the abundance ↑ in summer, winter & autumn - For *Ae. aegypti*, the abundance ↑ in spring
12.	Sadie J.R. et. al. 2019 (Sadie J. R. et al., 2019)	-	-	- ↑ *Ae. aegypti* during temp. between 21.3˚C-34˚C - ↑ *Ae. albopictus* during temp. between 19.9˚C-29.4˚C	-
13.	Dhimal et al. 2014 (Powell & Tabachnick, 2013)	- ↑ rainfall will ↓ abundance of *Aedes sp.*	↑ humidity: - ↓ abundance of *Aedes sp.* - ↓ *Aedes sp*. eggs	- ↑ temp. will ↑ *Aedes sp.*	-
14.	Da Rocha Taranto et al. 2015 (M. F. Da Rocha Taranto et al., 2015)	- ↑ rainfall ↑ *Aedes sp*. eggs - extreme rainfall will ↓ abundance of Aedes sp. eggs	-	- ↑ temp. will ↑ *Aedes sp*. eggs	-
15.	Betanzos-Reyes et al. 2018 (Walter Reed Biosystematics Unit, 2011)	- ↑ rainfall up to 70mm will ↑ *Aedes sp*. eggs - rainfall > 70mm will have no change in *Aedes sp*. eggs	- ↑ humidity 30-70% will ↑ abundance of *Aedes sp.* eggs - Humidity > 70% will ↓ abundance of *Aedes sp*. eggs	- ↑ *Aedes sp.* eggs during temp. between 12˚C-18˚C - ↓ *Aedes sp*. eggs during temp. >18˚C	--

16.	Da Cruz Ferreira et al. 2017 (Da Cruz Ferreira et al., 2017)	-	- ↑ humidity >75% will ↓ abundance of *Aedes sp.*	- ↑min. temp. >18˚C will ↑ abundance of *Aedes sp.*	Abundance of *Aedes sp.*: - ↓ in winter - ↑ in summer
17.	Bezerra et al. 2016 (Bezerra et al., 2016)	-	-	↑ *Ae. albopictus* during: - min. temp. between 12.1˚C-23.2˚C - max. temp. between 18.6˚C-34.2˚C	-
18.	Dhimal et al. 2015 (Dhimal et al., 2015.)	- ↑ rainfall will ↓ abundance of *Aedes sp.*	- ↑ humidity will ↓ abundance of *Aedes sp.*	- ↑ temp. will ↑ abundance of *Aedes sp.*	-
19.	Das et al. 2014 (Das et al., 2014)	-	-	- ↑ max temp. between 21.6˚C-34.3˚C will ↑ abundance of *Ae. albopictus* larvae density	-

Table 4: Newcastle Ottawa Quality Assessment Scale

No	Study	Selection				Comparability		Outcome		Quality score
		Representativeness of the sample	Sample size	Non-respondents	Ascertainment of the exposure (risk factor)	The study controls for the most important factor	The study control for any additional factor	Assessment of the outcome	Statistical test	
1.	Barrera et al. 2019 (Barrera et al., 2019)	*	*			*		**	*	6
2.	Roy et al. 2018 (Dhimal et al., 2014)		*		*	*		**	*	6
3.	Xiang et al. 2017 (Xiang et al., 2017)	*	*		**	*		**	*	8
4.	Phung et al. 2016 (Zainon, Mohd Rahim, Roslan, & Abd Samat, 2016)	*	*		*	*		**	*	7
5.	Limper et al. 2016 (Limper et al., 2016)	*	*		**	*		**	*	8
6.	Williams et al. 2015 (Williams et al., 2015)	*	*		**	*		**	*	8
7.	IM Nurin-Zulkifli et al. 2015 (IM Nurin-Zulkifli. et al., 2015)	*	*			*	*	**	*	7

8.	Taber E.D et. al. 2016 (Taber et al., 2017)	*	*		**	*		**	*	8
9.	Dutto M. & Mosca A. 2017 (Dutto & Mosca, 2017)		*		**	*		**	*	7
10.	Rodrigues et. al. 2015 (Rodrigues et al., 2015)	*	*	*	**	*		**	*	9
11.	Marta R.H.S. et. al. 2018 (Marta, 2018)	*	*		*	*		**	*	7
12.	Sadie J.R. et. al. 2019 (Sadie J. R. et al., 2019)			*	**	*		*	*	6
13.	Dhimal et al. 2014 (Dhimal et al., 2014)	*	*		*	*		**	*	7
14.	Da Rocha Taranto et al. 2015 (M. F. Da Rocha Taranto et al., 2015)	*	*		**	*		**	*	8
15.	Betanzos-Reyes et al. 2018 (Á. F. Betanzos-Reyes et al., 2018)	*	*		**	*		**	*	8
16.	Da Cruz Ferreira et al. 2017 (Da Cruz Ferreira et al., 2017)	*	*		**	*		**	*	8
17.	Bezerra et al. 2016 (Bezerra et al., 2016)	*	*		**	*		**	*	8
18.	Dhimal et al. 2015 (Maricopa County Environmental Services, 2006)	*	*		**	*		**	*	8
19.	Das et al. 2014 (Das et al., 2014)	*	*		**	*		**	*	8

Climate Components and Recommendation of Vector Control

Rainfall

Findings showed that extreme rainfall will cause reduction in vector abundance (Martinelle Ferreira da Rocha Taranto et al., 2015; Dhimal et al., 2015.; Dhimal et al., 2014; Rodrigues et al., 2015; Xiang et al., 2017), but the abundance increases post rainfall. This could be due to its catastrophic effects on a local population of vectors by constant washing of soil by flooding, reducing the vector habitat, leads to an inverse relation to vector intensity (Epstein, 2004). Rainfall up to 70mm is found to be the optimal for mosquito breeding, thus supportive factor towards Aedes species abundance in the environment (Ángel Francisco Betanzos-Reyes et al., 2018). A study done in Kuala Lumpur concluded that there was strong association between dengue cases and monthly rainfall, where incidence always preceded by rainy season (Aziz et al., 2014). In Tirunelveli, India where city has poor rainfall stored water in various containers for daily use, in which these containers became the main breeding habitats for Aedes mosquito, the situation is similar to root cause of urban dengue in Petaling Jaya District, Malaysia (Zainon et al., 2016). This result provided privilege of vector control which is in contrast with the conventional belief that rainy season causes increased in vector abundance, as 10mm rainfall and humidity of 30-70% only contributes to 1% of increased vector abundance (Phung et al., 2016). Therefore, increasing awareness for search and destroy of stagnant water bodies post rainfall is an effective measure to prevent vector breeding, as rainfall does not contribute to the increase of vector abundance, but the human activities do.

Temperature

Temperature change will lead towards change in incidence and prevalence of disease pattern by adjustment of vector's biting rates, human contacts, and also the vector abundance (Figueroa, 2015). Amazingly, vector Aedes species adapt well to temperature changes by changing their geographic distributions, and there is evidence that some have produced genetic adaptation to increasing temperatures (Patz et al., 2003). Any increase in the temperature will cause increase in growth rate of vectors, and decrease the extrinsic incubation period which may prolonged the pathogen's transmission period (Figueroa, 2015). The feeding frequency (estimated by biting rates), longevity of the mosquitoes and the time to virus replication (extrinsic incubation period) are highly sensitive to environmental temperature conditions (Caminade, McIntyre, & Jones, 2017). Both the Aedes species and viral life cycle exhibit non-linear relationships of transmission with temperature. A parabolic relationship with temperature is exhibited, where maximum biting performance occurs at optimum thermal zones, while lower or higher temperature than the optimum thermal zones exhibits lower vector performance in zero order, similar to previous findings (Liu-Helmersson et al., 2014). Our review showed that optimum temperature range of T_{min} 3.4˚Cto T_{max} 34.3˚C (minimum and maximum temperatures) is suitable for vector Aedes sp survival. At different temperature regimens the length of the Aedes aegypti life cycle showed variety of development rate. Faster development of life cycle recorded at temperature of 34◦C than at 32◦C, while most larvae found to be dead at temperature of 36◦C (Mohammed & Chadee, 2011). A study done also found almost the same findings, in which immature Aedes sp stage dead when temperature more than 34.5◦C (Chadee & Martinez, 2016). Malaysia weather is predicted to have 0.6-

1.2ºC rise of surface temperature in the next 50 years (1969-2009) and projected to increase another 1.5-2.0ºC by year 2050 (Begum, March 1, 2017; Ministry Of Natural Resources And Environment Malaysia, 2015).

This is clear evidence that climate conditions alterations such as global warming in sub-tropical countries has resulted in a regional temperature closer to the thermal optima, explaining the increased vector-borne disease transmission. At the same time, global warming of geopolitical regions of current flavivirus endemicity which is conducive to mosquito-borne diseases transmission may experience lower rate of disease transmission as the warming temperatures might move the environment away from the thermal optimum that becomes less favourable to the Aedes sp survival (Shragai T et al., 2017). Understanding temperature-vector survival relationship, health advises to modify time to daily outdoor activity, such rubber harvesting, palm oil harvesting and working in construction to noon hours where temperature peaks beyond the thermal comfort zone 3.4-34.2ºC may reduce human-vector contact. Heat modality above 34ºC can be used to destroy the vector habitat.

Humidity

The acceptable range for Aedes species survival would be around 30-70mm. The annual cumulative precipitation with is higher would strongly increase transmission for not only DENV but also ZIKV (Messina et al., 2016). In Malaysia, there was an average increase of 17% in one-hour duration and 29% in three hours duration of precipitation intensity in 2000-2017 when compared to 1971-1980) and is projected to experience increment in frequency of extremes weather within wet cycles (-5 to +9 ºC change in Peninsular Malaysia, -6 to +11 ºC in Sabah and Sarawak) by year 2050 (Begum, March 1, 2017; Ministry Of Natural Resources And Environment Malaysia, 2015). In the subtropics country of Brazil, an increase in humidity of more than 75% showed a reduction of Aedes species Density, similar to our review (Da Cruz Ferreira et al., 2017). The development cycle of larvae and pupae is also affected with the changing of humidity, where it varied from 5 to 42 days, with an average of 9.4 days at 24.3 °C and 62% relative humidity but an increase relative humidity reduced the duration of development cycles (Oliveira Custódio et al., 2019). Absolute humidity would also restrict the distribution from the drier areas and increase in coastal areas, this will lead to an increase in vector importation due to human and trade movement.

Since humidity beyond 70% does not favour survival of vector, in which Malaysia is having 70-72% of humidity and humidity is always associated with monsoon season; search and destroy activity should be intensify during dry season in April-September yearly, such as elimination of plastic containers, tyres, durian shells and coconut husks outdoor by the residence as well as local sewage management company and the local authority, dengue cases can be controlled. This is correlate with the data of increased dengue cases in Selangor and Johor compared to other states for the past 5 years in Malaysia, where both states have undergone rapid urbanization in recent years, which has introduced problem of worsen irrigation, sewage management due to increased population density and further displacement to high-risk environment, with pre-existing vulnerability due to low socioeconomic status.

By picking up this strong point, Communication for Behavioural Impact strategy used by the health authority (COMBI) shows important role in vector control for Aedes species both globally and in Malaysia.

Wind Velocity

In Malaysia, the optimum speed for survival and breeding of the mosquitoes are 0.05 ± 0.01 m/s. Higher wind speed will contribute to immature mosquitoes (N. Dom & Abu, 2013), whereas a slower wind speed will facilitate the production of larvAedes In Argentina, the average speed of more than 3km/h will lead to a reduced density in that area (Grech et al., 2019). Since the wind velocity affects the flight range of Aedes species mosquitoes, utilizing meteorological data in conjunction to Wolbachia release shall synergizes the success of biological control. Wolbachia infection to Aedes species aim to induce wingless female mosquito Aedes offspring, in which a high windspeed background can produce synergistic effect with it for the reduction of vector abundance. Having the optimal speed would help in the successful dispersion of the Wolbachia.(Liu, Sun, Wang, & Guo)

Strengths

The strength to this review is that no recent review on climate change in association with vector distribution or survival was done to the best of our knowledge. Secondly, specific analysis is done on different climate components in relation to vector distribution and survival. Recommendations of vector control are tailored to Malaysia setting utilizing review of climate change components. The quality of articles is being accessed narratively and objectively; combining articles on ecology, entomology, modelling and vector prevalence worldwide and the recommendations of vector control are tailored to local situations.

Limitations

Limitations encountered included only limited representative articles from Southeast Asian countries, particularly Malaysia, mmodeling studies gave general estimation without considering variation in microenvironment niche and also that most entomological / genetic studies that relates to climate change do not directly associate to prevalence of disease during study period. Lastly would be the possible dilutional effect of outcome from non-pathogenic carrying Aedes species has been controlled by article selection / inclusion.

Conclusion

In conclusion, we can conclude that climate components like rain fall, temperature, humidity, wind velocity and season affects the distribution of Aedes species Among all the components, the one that has the most effect on the mosquito density are the rainfall and temperature. Climate change expanded the transmission zone of dengue by latitude and altitude. Therefore, the climate factors should be considered in the planning and implementation process of mosquito control and prevention. By the implementation, improved outbreak prediction and detection through coordinated epidemiological, meteorological and entomological surveillance can be achieved. Also, by understanding their distributions, new technologies can be developed to reduce vector density and vector borne diseases.

List of Abbreviations

Aedes aegypti : *Aedes aegypti*

PRISMA: Preferred Reporting Items for Systematic Review and Meta-analysis

ZIKV: Zika Virus

DENV: Dengue virus

CHKV: Chikungunya Virus

YFV: Yellow fever virus

P.I.C.O.: population, intervention, comparison, outcome

COMBI: communication for behavioral impact

Conflicts of Interest

The author declares no conflicts of interest.

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