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How Do Climate Variables Affect the Transmission of Dengue Infection in South and Southeast Asia: A Scoping Review

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Abstract: Introduction: Dengue is an arboviral infection, transmitted from person to person via mosquito vectors. Dengue transmission is affected by rainfall, temperature, humidity and wind speed. These climate variables are changing as a result of anthropogenic climate change, and it is expected that this will affect the incidence of dengue. This scoping review explored the impacts on dengue transmission of variation in these climate variables in 12 Asian countries located in South- and South-East Asia regions. Methods: The protocol developed by the Joanna Briggs Institute was followed for this scoping review. Articles were found using the PubMed, Scopus, and Embase databases, as well as grey literature. Studies conducted in India, Bangladesh, Bhutan, the Democratic Republic of Korea, Indonesia, Maldives, Myanmar, Nepal, Thailand, Sri Lanka, and Timor Leste and published in English between 2002 and 2022 were included. An extensive literature search was conducted in February and March, 2022. A modified checklist designed for assessing the quality of ecological studies was used to assess the quality. Following quality assessment, ninety articles were included in the review. Results: The initial search yielded 1912 articles. After the duplicates were removed, 983 were identified as potentially relevant. Following the exclusion of 729 articles by two reviewers, 254 articles were subjected to full text screening. Thereafter, 90 articles were selected for the review that strictly met the inclusion criteria. Although the results were mixed, we found that dengue transmission decreases in temperature extremes. Dengue transmission increases with heavy rainfall, with a 1- 3-month lag. Humidity was also found to be related to dengue transmission. Other factors found to be associated with dengue transmission include the hours of sunshine and wind speed. Conclusion: There is a complex relationship between changing climate parameters and dengue incidence in Asia. This reflects the complex ecology of vector-borne diseases and suggests that the impact of changes in climate variables on dengue transmission may vary according to local climate and other factors.

Keywords: Dengue, Climate Change, Asia, Scoping Review

1. Introduction

Global average land and sea average temperatures are due to increasing greenhouse gases in the atmosphere. This is resulting in changes in weather patterns across the globe (United States Environmental Protection Agency, 2022). The past seven years (2015 – 2021) have been reported as the warmest years so far with a rise in the global mean temperature of 1.11 $\pm$ 0.13^{0}C above the 180 -1900 period (World Meteorological Organizaton, 2022). It is estimated that global temperature will be increased rapidly over the next few decades, causing changes in rainfall and precipitation (Intergovernmental panel on Climate Change, 2022). Mosquito breeding and vector competency is impacted by changes in climate variables such as temperature, humidity and rainfall (Chandra & Mukherjee, 2022).

Dengue is an arboviral infection predominantly transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes. *Ae aegypti* is the most efficient vector. These mosquitoes only breed in clean water (Higa, 2011). Dengue infection can be asymptomatic but may lead to dengue fever or Dengue Haemorrhagic Fever (DHF). Some cases can be severe, requiring hospitalization and can cause death. There are four dengue virus subtypes, DENV1, DENV 2, DENV3, DENV4 (World Health Organization, 2022a). Dengue is a vector-borne disease of public health concern. It has emerged as the most widespread and rapidly increasing vector borne disease in the world. Of the 3.5 billion people around the world living in dengue-endemic countries, 1.3 billion live in dengue-endemic areas in 10 countries of the South-East Asian (SEA) region. The SEA contributes to more than half of the global burden of dengue. The number of cases in this region has increased by 46% from 451,442 to 658,301 from year 2015 to 2019 period. Five SEA countries (India, Indonesia, Myanmar, Sri Lanka, and Thailand) are among the 30 most highly endemic countries in the world (World Health Organization, 2022b).

Dengue transmission is affected by host factors, vector density and environmental factors including climate and urbanization. Urbanization causes increased transmission of the disease due to increased population density and the formation of residual mosquito breeding places such as construction sites, slums and garbage (Gubler, 2011). Rainfall fills these sites with clean water suitable for mosquito breeding. In areas where there is a very low rainfall and interrupted water supply, collection of water in artificial containers like tanks increases mosquito breeding habitats. When there is heavy rainfall, a reduction in dengue transmission may occur due to the flushing away of mosquito eggs, larvae, and pupae (Benedum, Seidahmed, Eltahir, & Markuzon, 2018). Further, precipitation is identified as an important factor in providing habitat for aquatic stages of the mosquito cycle. Higher precipitation is associated with increased Aedes aegypti population (Barrera, Amador, & MacKay, 2011). Importantly, temperature can influence dengue transmission. Moderate increase in temperature shortens the extrinsic incubation period (EIP) and affects the viral replication within the vector and increase dengue transmission. The EIP of DENV 1 and DENV 2 in *Ae aegypti* mosquito is 9 days at 26°C - 28°C and 5 days at 30 °C (Watts, Burke, Harrison, Whitmire, & Nisalak, 1987). A small increase in DTR around the mean temperature also shortens the EIP (Lambrechts et al., 2011). Moreover, all four stages of *Ae aegypti* mosquito life cycle (eggs, larvae, pupae and adult) is affected by temperature including the female mosquito reproductive life cycle. As in many of the research, there is a parabolic relationship between maximum temperature and dengue (Seah, Aik, Ng, & Tam, 2021). Their fertilization decreases below 20 °C and oviposition cycles are accelerated in higher temperature levels. It affects the egg and immature mosquito development and the adult mosquitoes as well (De Garín, 2000). It has been found that the maximum survival of immature eggs, lower mean time to pupation in days and maximum percentage of larval survival occurs between 16 °C to 38 °C, with optimal survival at 26°C (Carrington, Seifert, Willits, Lambrechts, & Scott, 2013) while the cooler temperatures are not favourable for survival. It has been found that development of larvae and pupae of *Ae aegypti* is ceased in temperature less than 8.3°C (Rueda, Patel, & Stinner, 1990). The survival of the adult mosquito beyond the EIP is important in transmission of dengue because viral replication in the vector host is necessary for transmission. Adult mosquitoes take their first blood meal three days after being an adult. They become vectors after the EIP and they are unable to survive in extreme temperatures (less than 0°C and more than 40°C) According to Lambrechts et al., 2011, life span of adult *Ae aegypti* mosquitoes is more in lower DTR compared to higher DTR (Lambrechts, Paaijmans, Carrington L, Thomas, & Scott, 2011). When the vector mosquito density in an area is increased, the host – vector ratio becomes high and the biting rate of humans by mosquitoes also increase. These factors contribute to the vectoral capacity which determines the spread of dengue. Further, it has been understood by a modelling study done in few countries in south-east asia, that *A. aegypti* population increases in the warmest months (April – June) in the region (Osuolale, 2023).

Although there is clear evidence as to how the variation in temperature affects *Ae aegypti*, effect of humidity seems to be more complex. Although it has explained that feeding activity, survival and egg development is increased in *Ae aegypti* mosquitoes at high humidity, there is an interaction with temperature (OECD, 2018). A study in Brazil has brought to light that at 25 ºC and 80% relative humidity, *Ae aegypti* female mosquitoes survived two-fold more and produced 40% more eggs when compared to those kept at 35 ºC and 80% relative humidity. However, in 45% of females kept at 35 ºC and 60% relative humidity oviposition was inhibited and only 15% females laid more than 100 eggs, suggesting that the intensity of the temperature effect was influenced by lower humidity. Gradual reductions in egg fertility at 60% relative humidity were observed with the increase in temperature whereas such effect was not found in 80% relative humidity at 25^{0}C and 30 ^{0}C. These results suggest that the reduction in population densities recorded in tropical areas during seasons when temperatures reach over 35 ºC is likely to be strongly influenced by temperature and humidity (Costa, Santos, Correia, & Albuquerque, 2010) . A comparison of infection rate, dissemination rate and population transmission rates of *Ae albopictus*, with the fluctuating temperature (18°C, 23°C, 28°C and 32°C) has shown that all of these parameters are at their highest at 32 °C (Liu et al., 2017). However, extreme temperature seems to increase mosquito mortality followed by a reduced risk in the transmission of the virus. Research done in Thailand has revealed that minimum and average daily temperature is associated with female *Ae aegypti* mosquito abundance. The proportion of parous mosquitoes had been highest during the dry season (Scott et al., 2000). Most importantly, different components of climate interact with each other in a complex manner. Therefore, the relationship between the change in climate variables and its effect in dengue has also been found to be multifaceted. For example, higher precipitation and high temperature leads to increased humidity in the environment. Although the effect of these individual parameters has been identified in the laboratory settings, it is a combination of these variables which affect dengue in the environment. Thus, the combined effect of different parameters of climate act differently in different contexts (Xu et al., 2017).

The aim of this scoping review is to assess how change in climate variables has affected Dengue infection in the South Asia and SEA regions. It will assist the health authorities of countries in those regions to plan for the implementation of preventive measures to minimize the spread of dengue infection (Center for Disease Control and Prevention, 2021).

2. Methods

This scoping review was conducted according to the protocol developed by the Joanna Briggs Institute (JBI) (The Joanna Briggs Institute, 2015). The main considerations of the JBI review protocol (study objective, inclusion criteria, search strategy, data extraction and presentation of results) were observed. This study was registered in the International Prospective Register of Systematic Reviews PROSPERO 2022 CRD4202231316.

2.1. Selection criteria

Peer reviewed articles, discussion papers, briefings, dissertations and thesis, conference proceedings, fact sheets, manuscripts, and unpublished papers which described the effect of climate change on dengue infection or its vectors *(Ae aegypti and Ae Albopictus)* or predicted its effect were included in the review. Studies which were conducted in India, Bangladesh, Bhutan, Democratic republic of Korea, Indonesia, Maldives, Myanmar, Nepal, Thailand, Sri Lanka and Timor Leste published during 2002 – 2022 period, in English language were included. Although it was planned to include articles in Sinhala language as it is the mother tongue of the authors, there were no articles published in Sinhala language. Therefore, only articles in English language were included in the review. Articles in other languages were excluded due to unavailability of funding for translation. Review articles on climate change and dengue were excluded.

2.2. Search Strategy

An advanced literature search was conducted in February and March 2022. The electronic data bases Pubmed, Scopus, and Embase were used to find peer reviewed journal articles whereas Google scholar, and ProQuest to search for grey literature. A general search in Google search engine was also done [Refer Supplementary file.01].

2.3. Data Extraction

The principal author (MF) did the preliminary search of the articles from different sources mentioned above. They were managed and duplicates were removed using EndNote version 20 (The EndNote Team, 2013). The articles were uploaded to Rayyan software for screening purposes (Mourad Ouzzani, 2016). At the first stage, both MF and RMNUR screened for title and abstracts blindly and there were no conflicts on any decisions. Then full text screening of the selected articles was conducted by the same reviewers. In cases where there were conflicts regarding the decision, opinion of the supervisor was considered. Finally, the articles which strictly met the inclusion criteria were included in the review. Due to the heterogeneity of the studies, a meta-analysis of the results was not feasible. The findings are reported as a narrative synthesis.

2.4. Quality Assessment

As the majority of the studies included in the review were ecological in design, a modified scale of a checklist designed for quality assessment of ecological studies was used (Dufault & Klar, 2011). The quality assessment was based on 10 items with a maximum overall score of 12 points. For each item, if a study did not meet the criteria the item was given a score of "0", otherwise it received a score of "1", or "2". The grade of the studies was labelled: low

(< 5 points); medium (5-8 points) and high relevance (> 8 points) (Extraction data available as supplementary data file 02).

3. Results

Initially, 1912 articles were yielded from the initial search, including 483 articles from PubMed, 827 from Scopus, 426 from Embase and 176 from Google Scholar. Endnote version 20 was used to remove duplicates. After removing the duplicates, 983 were identified as potentially relevant. Those articles were subjected to title and abstract screening. This was done by two independent reviewers. After excluding 729 articles according to both reviewers' opinion, 254 articles were subjected to full text screening. Following that, 90 articles which strictly met the inclusion criteria were selected for the scoping review. The details are illustrated in figure 1.

Among the articles included in the study, the majority of the studies have been conducted in Indonesia (n= 29) while the least have been conducted in Bangladesh (n= 5). Data for the studies have been taken during different periods of time between the period of 1979 to 2019.

Following the quality assessment 13 articles were identified as low, 71 articles were identified as medium, and six articles were identified as high quality.

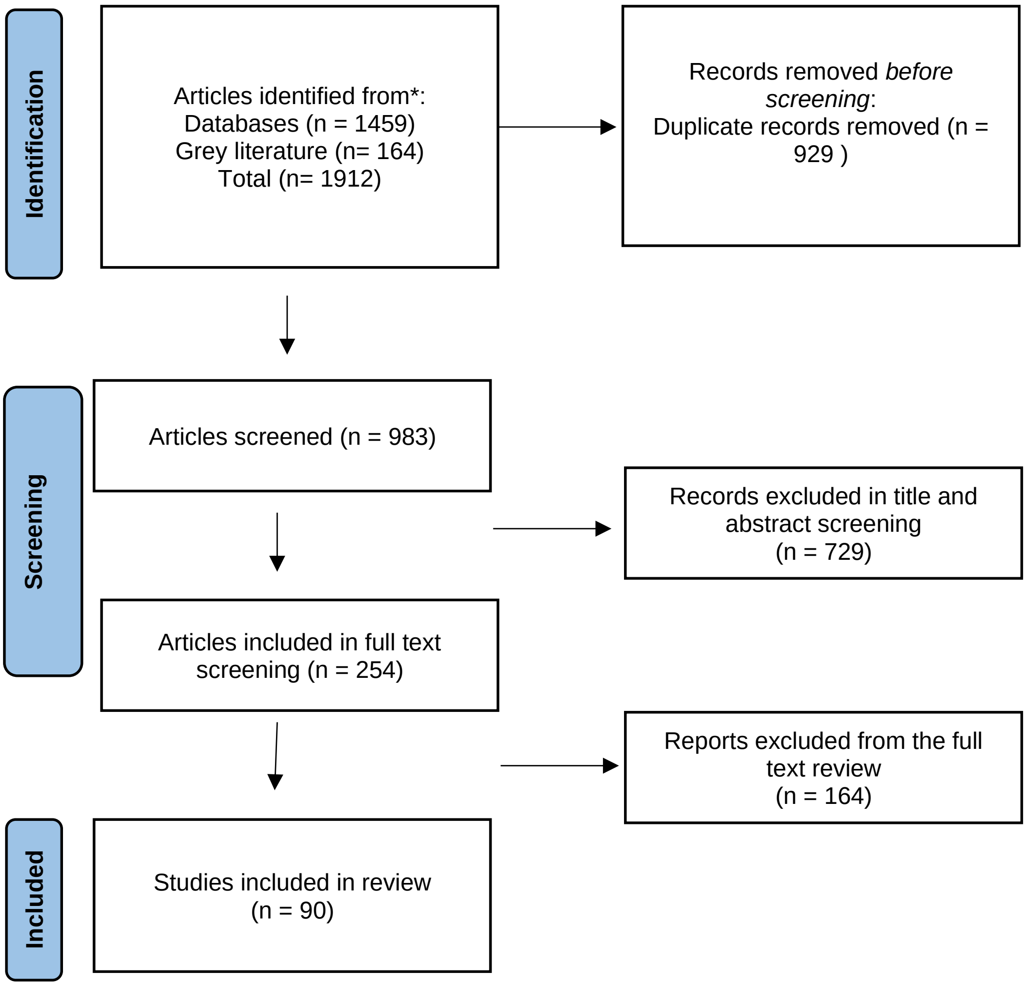

Figure 1. PRISMA flow diagram

3.1. Variables Included in the Studies

Dependent variables were either dengue fever case numbers or variables related to the vector mosquitoes. Most of the articles (n=75, 83.3%) have calculated dengue fever incidence using dengue fever case numbers and estimated population data for the area concerned. Most of the dengue data were extracted from the government health offices of relevant countries. Only three studies have used data which were primarily collected for the study (Chaiphongpachara, Pimsuka, Na Ayudhaya, & Wassanasompong, 2017; Mukhtar et al., 2021; Roy, Gupta, Chopra, Meena, & Aggarwal, 2018). Different mosquito-related variables were included as dependent variables in fifteen articles. House index (percentage of houses positive for larvae), Bretaux index (number of positive containers for 100 houses) and container index (number of infected containers pr 100 containers) (Garjito et al., 2020) were taken as dependent variables in three articles (Channa & Memon, 2020; Paul et al., 2018; M. Rahman et al., 2021).

The main climate variables included in the studies were temperature, rainfall, humidity and precipitation. The impacts of temperature variables were assessed by 88 articles. The temperature related variables included in the articles were average temperature, maximum temperature, minimum temperature, daytime and night time land surface temperature, diurnal temperature range, indoor & out door temperature, and water temperature in containers. Some studies have considered daily temperature while other have considered monthly values. The impacts of rainfall were assessed by 65 studies. The rainfall variables were annual accumulated rainfall, average monthly, weekly & daily rainfall maximum, minimum and average rainfall and total number of rainy days. Precipitation has been addressed in seven studies. The impacts of humidity were assessed in 43 studies. Annual relative humidity, mean, maximum and minimum humidity and weekly relative humidity were humidity variables used in those studies. Other climate related variables included in the studies were barometric pressure, (Sriklin, Kajornkasirat, & Puttinaovarat, 2021), average maximum wind speed(Ahmed & Siddiqui, 2014; Arsin et al., 2020), wind velocity (*IOP Conference Series: Earth and Environmental Science*, 2018); Ishak & Kasman, 2018; (Harumy & Ginting, 2021; Jat & Mala, 2017; Minarti et al., 2021); Harumy & Ginting, 2021(Ishak & Kasman, 2018) annual sunshine duration (Jaya & Folmer, 2021) and dew point in a day (Sahay, 2018). Most of the climate related data were obtained from the government mereological departments of relevant countries except in 28 articles where satellite data on climate were used.

3.2. Analytical Approaches

Different analytical methods have been used in the article selected in this review. Most of the studies have used either a univariate analysis, bi variable analysis or multi variate analysis. Ali et al, 2020 have used spearman test (Ali, Ma'rufi, Wiranto, & Fuad, 2020) while Pearson correlation was performed in (Chandran & Azeez, 2015; U. Khairunisa, Wahyuningsih, Suhartono, & Hapsari, 2018; Pichainarong, Mongkalangoon, Kalayanarooj, & Chaveepojnkamjorn, 2006; Rusli & Yushananta, 2020; Salam, 2018); (U. Khairunisa et al., 2018); (Wijegunawardana et al., 2019). Arcari et al, 2017 have done a stepwise regression analysis (Arcari & Tapper, 2017) and Acharya et al, 2018 have performed a generalized linear model, followed with a multi variate analysis (Acharya et al., 2018). Linear regression has been done to analyze the correlation between climate variables and dengue variables in two articles (Noppradit et al., 2021; Sripugdee, Inmoung, & Junggoth, 2010). GIS analysis has been used along with regression analysis in one article (Khalid, Bueh, & Ghaffar, 2021). Poison regression model has been used in another (K. M. Rahman et al., 2020). Auto Regressive Integrated Moving Average (ARIMA) model was used in two articles (Shashvat, Basu, & Bhondekar, 2021) (Zahirul Islam et al., 2018). Time series analysis was used in two articles (Goto et al., 2013; Salim & Syairaji, 2020). Wavelet time series analysis has been performed in one article (Ehelepola, Ariyaratne, Buddhadasa, Ratnayake, & Wickramasinghe, 2015).

3.3. Impact of Temperature on Dengue

Among the 90 articles included in the study, 65 articles have studied the impact of temperature on Dengue. Summary of the articles are given in table 3 in supplementary data. Nine studies have been conducted in India, 4 in Bangladesh, 25 in Indonesia, 09 in Pakistan, one in Nepal, 08 in Sri Lanka, 07 in Thailand only, 01 in Thailand and Singapore and one in a region consisting of Bangladesh, Thailand, Myanmar, India, Philippine, Sri Lanka. Most of the studies have shown a positive association between moderate temperature and dengue incidence (Anno et al., 2014; Arsin et al., 2020; Campbell, 2014; Joshua, Kaliaperumal, Krishnamurthy, Muthusamy, Venkatachalam, Gowri, Shete, Ramasamy, Gupta, & Murhekar, 2020; Joshua, Kaliaperumal, Krishnamurthy, Muthusamy, Venkatachalam, Gowri, Shete, Ramasamy, Gupta, Murhekar, et al., 2020; Khalid et al., 2021; Salamah, Kuswanto, & Yussanti, 2012). One study has shown the negative association between maximum temperature and dengue incidence (S Wongkoon, Jaroensutasinee, & Jaroensutasinee, 2013).

In contrast to the evidence mentioned above, one study has shown negative association between temperature and dengue incidence (Ummi Khairunisa & Wahyuningsih, 2018) and few studies conducted in Thailand, India and Sri Lanka have shown that there is no significant association between temperature and dengue (Chaiphongpachara et al., 2017); ;(S. A. Rahman, Rahim, & Mallongi, 2018; Salam, 2018); Wijegunawardana et al., 2019; (Goto et al., 2013; Noppradit et al., 2021; Wijegunawardana et al., 2019).

3.4. Impact of Temperature on Mosquito Related Indices

A study conducted in Lahore, Pakistan during 2011 – 2013 period has revealed that the association between Ovitrap Index (OI) (the number of ovitraps containing aedes eggs or immature mosquitos in the total ovitraps observed) and temperature in early rainy season (p=0.133), late rainy seasons (p=-0.823) were not significant while it was significant in early post-rainy (p=-0.000), late post-rainy seasons (p=0.024) (Qureshi, Tabinda, & Vehra, 2017).

According to a study in Pakistan during July 2016 – June 2017 period, Container index (CI) was highest when the minimum temp was between 17 - 24 °C, maximum temperature was between 32.5 - 36.5 °C. During this study period the minimum temperature varied from 11- 27.6 ^{0}C and maximum temperature has varied from 22 – 42 ^{0}C (Channa & Memon, 2020).

A study in Nepal during 2011 – 2012 period revealed that each degree rise in mean temperature has shown an increase in *Ae aegypti and Ae albopictus* abundance (Dhimal et al., 2015). This was supported by a study in Indonesia in 2019 which revealed that there is a positive correlation between temperature and *Ae aegypti and Ae albopictus* larvae (Ratnasari et al., 2020). However, another study has proven that each degree rise in mean temperature by one degree Celsius was associated with a decrease in the mean *Ae aegypti and Ae albopictus* mosquito number by 6.49 (95%CI: - 12.4 - 0.58; p= 0.032) (Paul et al., 2018).

Density of *Ae. albopictus* was positively correlated with temperature (Pearson correlation = 0.79; $p < 0.001$) in four different cities in Pakistan (Rawalpindi, Islamabad, Abbotabad and Mansehra) in during July to September 2012 (Khan, Tahir, Ahsan, Malik, & Butt, 2014).

3.5. Impact of Rainfall on Dengue

Eighteen articles which have studied the relationship between the number of rainy days and dengue cases have shown a strong significant relationship (Ali & Ma'Rufi, 2018; Anno et al., 2014) (Chandran & Azeez, 2015) ; (Ehelepola et al., 2015); (Minarti et al., 2021; S. A. Rahman et al., 2018; Rusli & Yushananta, 2020) (Ummi Khairunisa & Wahyuningsih, 2018; Nair & Aravind, 2020; K. M. Rahman et al., 2020; Sriklin et al., 2021; Sripugdee et al., 2010).

Evidence from a study from Indonesia and Thailand have shown a significant positive correlation between rainfall at two months lag and the number of dengue cases (Polwiang, 2016; Shashvat et al., 2021). Muurlink et al,2018 have revealed that the best predictors of an dengue outbreak are the number of rainy days in the preceding two months (Muurlink, Stephenson, Islam, & Taylor-Robinson, 2018). According to studies conducted in Indonesia and India, there is a significant association between cumulative rainfall (Ali et al., 2020; Arcari & Tapper, 2017; Arcari, Tapper, & Pfueller, 2007; Joshua, Kaliaperumal, Krishnamurthy, Muthusamy, Venkatachalam, Gowri, Shete, Ramasamy, Gupta, Murhekar, et al., 2020; Riyanto et al., 2020; Roy et al., 2018; Salamah et al., 2012). A significant weak correlation between higher rainfall and incidence of DHF cases has been found in two studies conducted in Indonesia (Haryanto, 2016);(Salim & Syairaji, 2020).

In contrast to the above findings, a study conducted in Pakistan revealed that that the highest occurrence of dengue was reported when the rainfall is low (Fareed, Ghaffar, & Malik, 2016). This evidence is supported by the findings of a study conducted in Bangladesh, India and Sri Lanka and Pakistan (Islam, Emdad Haque, Hossain, & Hanesiak, 2021; Netrananda & Mani, 2021); (Mukhtar et al., 2021). Studies from Thailand, India and Sri Lanka have revealed that there is no significant association between dengue and rainfall (Chaiphongpachara et al., 2017; Goto et al., 2013; Noppradit et al., 2021; Pandey et al., 2012; Salam, 2018; Wijegunawardana et al., 2019).

3.6. Impact of Rainfall on *Ae Aegypti* and *Ae Albopictus* Mosquito Related Indices

A study conducted in Indonesia during 2014 – 2018 period revealed that number of mosquito larvae tends to increase in the rainy season (Zamli et al., 2019). Further, there had been a rainfall of 131.8 mm before the peak of container index was noted (Channa & Memon, 2020).

A study in Nepal during 2011 – 2012 period, has revealed a decrease in *Ae. aegypti and Ae. albopictus* abundance with increase in rainfall (Dhimal et al., 2015). In contrast, another study in Pakistan which revealed that the *Ae. albopictus* population was maximum during the rainy season (Nasir et al., 2018). Further, an entomological survey carried out in Bangladesh revealed that each mm increase in total rainfall was associated with a decrease in the mean number of immature *Ae aegypti and Ae albopictus* mosquitoes per positive container by 0.04 (95% CI: -0.08, -0.01; p = 0.024) (Paul et al., 2018). Density of *Ae albopictus* was positively correlated with rainfall in another study done in Pakistan (Pearson correlation = 0.95; $p < 0.001$) (Khan et al., 2014).

3.7. Impact of Precipitation on Dengue

Precipitation was found to have the strongest correlation with dengue cases with a lag time of eight weeks (correlation coefficient 0.363, p-value <0.05) in a study conducted in Pakistan during 2007 – 2011 period (Baig & Nawaz, 2012).

According to a study done in Indonesia during 2012 – 2016 period, precipitation is negatively associated with relative risk of dengue. Their results revealed that for 1% increase in monthly average precipitation, the relative risk of dengue decreases by 13.8%, 16.4%, and 8.5% for a zero, one, and two-month lag, respectively. According to a study conducted in Thailand during 1982 – 2013, it has been found that there is a 3 % increase in dengue relative risk for a unit increase in precipitation (Lowe, Cazelles, Paul, & Rodó, 2016).

A study done in Indonesia during the period of 2013 – 2019 has shown that there 0.0005 increase for 1mm precipitation (2 months lag) (Maulana et al., 2021).

3.8. Impact of Humidity on Dengue

A study conducted by Ali et al, 2020, using data during the period of 2012 – 2016, it was shown that there is a strong correlation between minimum humidity for one-month lag and DHF cases. The IRR for DHF cases for minimum humidity with a three months lag period was 1.030 (Ali et al., 2020). This evidence is also supported by the results of a study conducted in Indonesia during the period of 2014 – 2018 which shows that there is a correlation between relative humidity and DHF incidence, which is statistically significant (r = 0.413, p= 0.001) (Arsin et al., 2020). This is also supported by a Sri Lankan study, Bangladesh study, three Indonesian studies, Indian study and an Thailand study (Ehelepola et al., 2015); (Islam et al., 2021; Jat & Mala, 2017) (Roy et al., 2018) Tosepu et al., 2018; (Ummi Khairunisa & Wahyuningsih, 2018; Salim & Syairaji, 2020; Tosepu, Tantrakarnapa, Worakhunpiset, & Nakhapakorn, 2018).

According to a study done in Indonesia during 2012- 2016 period, the relative risk of Dengue is predicted to rise by 22.1%, 21.8%, and 25.8% for 1% increase in monthly average humidity at zero, one, and two-month lags (Jaya & Folmer, 2021).

A study conducted in Thailand during the period of 2014 – 2015 revealed that there was no significant association between humidity and dengue (Chaiphongpachara et al., 2017). This was also supported by the evidence from a study conducted in Thailand during 1982 – 2018 period (Noppradit et al., 2021) and a study from India considering data from 2014 – 2017 period (Shashvat et al., 2021).

Findings of a study conducted in Indonesia, have shown that an increase in the dengue fever cases with 1% decrease in relative humidity (Husnina, Clements, & Wangdi, 2019). On the contrary, an Indonesian study conducted during 2011 – 2017 period revealed that higher number of DHF cases are reported in areas with increased humidity (Riyanto et al., 2020). This is also supported by the evidence from a study conducted in Thailand which revealed that the maximum incidence of DHF cases occur at mean humidity of >80% and minimum humidity >62% (Campbell, 2014).

According to a study conducted in Sri Lanka, negative correlations between dengue incidence and a DHR (daily humidity range) >20% with 3.3-week and 4-week lag periods, has been found. Additionally, positive correlations between dengue incidence and DHR < 15% with 3- and 4-week lag periods was discovered (N. D. Ehelepola & K. Ariyaratne, 2015).

A study done in Indonesia during the period of 2014 – 2019 period and two studies in India showed that there is no significant association between the number of dengue cases and humidity (Harumy & Ginting, 2021).

According to a study in Indonesia during 2013 – 2019 period, the number of dengue cases has increased by 0.0143 for 1% humidity (Maulana et al., 2021). A study conducted in Indonesia during the period of 2003 – 2010 revealed that the dengue incidence will decrease with humidity of 70 to 75% and it will increase with humidity of 82 to 87%. Dengue will also increase under humidity of below 70% (Salamah et al., 2012).

3.9. Impact of Humidity on *Ae Aegypti and Ae Albopictus* Mosquito Related Indices

Container Index (CI) was highest when the relative humidity was between 50 % - 67% (Channa & Memon, 2020). According to a study in Nepal during 2011 – 2012 period, the *Ae. Aegypti* abundance has decreased and *Ae. albopictus* abundance has increased with increase in relative humidity (Dhimal et al., 2015). Relative humidity in previous 30 days of survey had a significant positive impact on *Aedes* abundance, as the mean number of mosquitos increased by the rise of relative humidity (Beta = 2.73, 95% CI: 0.59 - 4.88, p = 0.014) (Paul et al., 2018).

3.10. Impact of Wind on Dengue

According to a study conducted in Pakistan during the period of 2011 – 2012, it has been revealed that low wind speed prevents dengue outbreak (Ahmed & Siddiqui, 2014). This evidence is also supported by the findings of the study conducted during the period of 2010 – 2015 in India which found that there is a relationship between wind speed and DF cases (R^2= 0.06) (Jat & Mala, 2017). Further a study conducted in Indonesia has revealed that there is a strong correlation between wind speed and DHF incidence (r = 0.76). However, this finding has found to be statistically not significant (r= 0.76, p=0.492) (Minarti et al., 2021). Apart from the above findings, five studies included in the review have concluded that there is no correlation between wind speed and DHF incidence or dengue cases (Arsin et al., 2020; Harumy & Ginting, 2021; Noppradit et al., 2021; S. A. Rahman et al., 2018).

In contrast to the above findings, Ehelepola et al in 2015 have found that there is a negative relationship between wind run and dengue cases in a district in Sri Lanka during the period of 2003 - 2012 (Ehelepola et al., 2015).

3.11. Impact of Sunshine on Dengue

A study conducted in Indonesia during the period of 2012 – 2016 has revealed that sunshine duration has different effects for different time lags. The relative risk of Dengue decreases by 15.4% with a contemporaneous increase of monthly sunshine duration by 1%. There are positive impacts for one and two-month lags. The relative risk of dengue is predicted to increase by 21.5% and 7.6% for a 1% increase in monthly average sunshine duration at one and two-month lags (Jaya & Folmer, 2021). Wongkoon et al, 2012 also revealed that sunshine was negatively correlated with dengue incidence at a lag of zero to three months (S. Wongkoon, Jaroensutasinee, & Jaroensutasinee, 2012). In contrast to the above findings, a study conducted in Thailand, taking the climate data and dengue data during the period from 1982 – 2018 revealed that there is no statistically significant relationship between dengue cases and sunshine duration (Noppradit et al., 2021). This is supported by a study done in Indonesia which has shown a non-statistically significant weak relationship between sunshine and dengue cases (r = 0.008; p = 0.865) (Minarti et al., 2021). According to Noppradit et al, 2021, there is no significant association between sunshine and dengue (Noppradit et al., 2021).

3.12. Impact of Air Pressure on Dengue

According to study conducted in three provinces in Thailand (Pattani, Yala and Narathiwat) during the period of 2015 – 2019, air pressure was negatively correlated with the number of dengue cases. Spearman's rank correlation test has been used in analysis (Sriklin et al., 2021).

4. Discussion

This review is important because it collates evidence on impact of climate change on dengue in South Asian and SEA regions. This review analyses studies providing evidence on many climate variables. The majority of the articles which have studied the effect of temperature on dengue incidence have concluded that there is a positive association between moderate temperature between 25 ^{0}C – 34 ^{0}C and dengue incidence (Ajim Ali & Ahmad, 2018; Ali et al., 2020; Anno et al., 2014; Anwar et al., 2019; Arcari & Tapper, 2017; Arsin et al., 2020; Campbell, 2014; N. Ehelepola & K. Ariyaratne, 2015; Haryanto, 2016; Joshua, Kaliaperumal, Krishnamurthy, Muthusamy, Venkatachalam, Gowri, Shete, Ramasamy, Gupta, & Murhekar, 2020; Joshua, Kaliaperumal, Krishnamurthy, Muthusamy, Venkatachalam, Gowri, Shete, Ramasamy, Gupta, Murhekar, et al., 2020; Khalid et al., 2021; Lowe et al., 2016; Netrananda & Mani, 2021; Polwiang, 2016; Roy et al., 2018; Salamah et al., 2012; Salim & Syairaji, 2020; Sriklin et al., 2021) . One study has shown the negative association between maximum temperature and dengue incidence (S Wongkoon et al., 2013). Most of the articles which have studied the relationship between the number of rainy days and dengue cases have shown a strong significant relationship (Gama & Nakagoshi, 2013; (Ali & Ma'Rufi, 2018; Anno et al., 2014); (Chandran & Azeez, 2015) (Ehelepola et al., 2015); Ali & Ma'Rufi, 2018; Rahman et al., 2018; Ummi Khairunisa & Wahyuningsih, 2018; Ishak & Kasman, 2018; Tosepu et al., 2018; Supadmi et al., 2019; (Minarti et al., 2021; S. A. Rahman et al., 2018; Rusli & Yushananta, 2020) Nair & Aravind, 2020; Minarti et al., 2021;(Dutta et al., 2021); (Ishak & Kasman, 2018; Ummi Khairunisa & Wahyuningsih, 2018; Nair & Aravind, 2020; Sriklin et al., 2021; Supadmi, Perwitasari, Abdulah, & Suwantika, 2019; Tosepu et al., 2018). In contrast to the above findings, few studies have shown a negative relationship between dengue fever and rainfall (Fareed et al., 2016);(Islam et al., 2021; Netrananda & Mani, 2021); (Mukhtar et al., 2021). Further, a correlation between humidity and dengue has been identified by most of the studies (Anno et al., 2014; Arsin et al., 2020; Ehelepola et al., 2015; Islam et al., 2021; Jat & Mala, 2017) Ummi Khairunisa & Wahyuningsih, 2018; Tosepu et al., 2018; (Roy et al., 2018) Arsin et al., 2020; Salim & Syairaji, 2020; Ali et al., 2020; (Minarti et al., 2021) (Sriklin et al., 2021) Islam et al., 2021 (Ummi Khairunisa & Wahyuningsih, 2018; Salim & Syairaji, 2020; Tosepu et al., 2018). According to the findings of studies which have included wind speed, one study has revealed that low wind speed prevents dengue outbreak (Ahmed & Siddiqui, 2014) while another study has found a strong correlation between wind speed and DHF incidence (Minarti et al., 2021). In contrast, five studies included in the review have concluded that there is no correlation between wind speed and DHF incidence or dengue cases (Arsin et al., 2020; Harumy & Ginting, 2021; Noppradit et al., 2021; S. A. Rahman et al., 2018). Two studies which have measure the effect of sunshine on dengue has revealed that there is a negative relationship between sunshine (Jaya & Folmer, 2021; S. Wongkoon et al., 2012), one has revealed that there is no statistically significant relationship between dengue cases and sunshine duration (Noppradit et al., 2021) and another study has shown no significant association between sunshine and dengue (Noppradit et al., 2021). Only one study has which has assessed the effect of air pressure and dengue in this review, which revealed a negative correlation (Sriklin et al., 2021).

Although it has been concluded that temperature range between 25 – 34^{0}C has a positive association with dengue in this review, a study conducted in 20 Colombian cities during 2012 – 2015 period has concluded that average and maximum temperatures greater than 28°C and 32°C, respectively, had an inversely related relationship to dengue incidence (Peña-García, Triana-Chávez, & Arboleda-Sánchez, 2017). The probable reason for this difference could be the adaptation of the *Ae aegypti and Ae albopictus* mosquitoes in different geographical settings. As similar to the findings in this review, study conducted during 2003 – 2010 in Brazil has reported that there is a positive association between number of dengue cases and rainfall lag per three months (Silva, dos Santos, Corrêa Rda, & Caldas Ade, 2016). A study conducted in Burkina Faso in Sub Saharan Africa has shown that the effect of humidity on dengue was similar to the findings in the review, which revealed an increase in dengue cases with maximum humidity of 15 to 45% and then from 60 – 70% (Ouattara et al., 2022).

Different results have been observed in the studies selected in the review. The probable reason could be that the studies have been conducted in different geographical locations. Although measures have been taken at the planning stage of the systematic review to concentrate the review to studies from a region with similar climate variation, there are variations in the countries considered in this review as well. In some studies, data have been taken from few locations such as districts, provinces in one country whereas national level data have been taken in others. There two studies where more than one country have been taken as study location.

Although all the studies have described the climate variables such as temperature, rainfall, humidity, wind speed, sunshine and air pressure, the different variables have been measured in different studies. For example, different variables with regard to temperature such as maximum, minimum and mean temperature, daily temperature range have been measured under temperature while weekly rainfall, annual rainfall and number of rainy days have been measured under rainfall. Average humidity, minimum humidity, maximum humidity, average annual humidity, monthly average humidity has been measured under humidity.

The variation of results also could be due to the difference in source of data. The difference in the definition of dengue cases have also contributed to this difference. Some studies have taken all the notified dengue cases which have been confirmed clinically, while some have considered laboratory confirmed cases only. There can be instances where few other infections such as Leptospirosis and Chikungunya which are also common in this region may mimic as dengue, there could be a misclassification bias. Further, some studies have looked at the DHF cases as the dependent variable. Since all the dengue cases does not progress into DHF this also can be identified as a limitation.

There is a wide range of analytical methods used in data analysis of the studies selected in this review. This could also have resulted in variation in the results generated from the studies.

Only 12 countries of South Asia and SEA region were included in the study and articles published in the past 20 years are two main limitations in the study.

As dengue is on the rise specially in South Asian and SEA region, the findings of this review will be very useful to predict the dengue outbreaks according to weather forecast and implement preventive strategies accordingly.

5. Conclusion

It is complex how the change in climate variables affect dengue in Asian region. However, the evidence suggests that the transmission of dengue is decreased in extremes of temperature. Dengue infection tends to increase with a lag of 1 – 3 months of high rainfall. However, dengue cases tend to decrease with very high rainfall. Dengue infection seems to prefer high humidity level. Low wind speed tends to lower the transmission of dengue while moderate wind speed has a positive correlation on dengue. Sunshine also has a positive association on dengue transmission while air pressure seems to be negatively associated with dengue transmission. Since the number of studies conducted to measure the effect of climate parameters such as wind speed, air pressure, and sunshine on dengue in South Asian and SEA regions have shown to be low, more studies need to be conducted in this regard to generate concrete evidence.

References

Acharya, B.K., Cao, C., Xu, M., Khanal, L., Naeem, S., & Pandit, S. (2018). Temporal variations and associated remotely sensed environmental variables of dengue fever in Chitwan District, Nepal. *ISPRS International Journal of Geo-Information*, 7(7), 275. https://doi.org/10.3390/ijgi7070275

Ahmed, S.A., & Siddiqui, J.S. (2014). Principal component analysis to explore climatic variability and dengue outbreak in Lahore. *Pakistan Journal of Statistics and Operation Research*, 10(2), 247-256. https://doi.org/10.18187/pjsor.v10i2.686

Ajim Ali, S., & Ahmad, A. (2018). Using analytic hierarchy process with GIS for Dengue risk mapping in Kolkata Municipal Corporation, West Bengal, India. *Spatial Information Research*, 26(4), 449-469. https://doi.org/10.1007/s41324-018-0187-x

Ali, K., & Ma'Rufi, I. (2018). The relationship between rainfall and dengue hemorrhagic fever incidence during 2009-2013 (Case study at Grati and Tutur Sub-district, Pasuruan, Indonesia). *Paper presented at the 3rd International Conference on Climate* Change, *ICCC 2018.* https://doi.org/10.1088/1755-1315/200/1/012031

Ali, K., Ma'rufi, I., Wiranto, & Fuad, A. (2020). Variability of Local Weather as Early Warning for Dengue Hemorrhagic Fever Outbreak in Indonesia. *Paper presented at the 10th International Conference on Bioscience, Biochemistry and Bioinformatics, ICBBB 2020*. https://doi.org/10.1145/3386052.3386078

Anno, S., Imaoka, K., Tadono, T., Igarashi, T., Sivaganesh, S., Kannathasan, S., Surendran, S. N. (2014). Characterization of the temporal and spatial dynamics of the dengue epidemic in northern Sri Lanka. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives),* 8 163–166. https://doi.org/10.5194/isprsarchives-XL-8-163-2014

Anwar, A., Khan, N., Ayub, M., Nawaz, F., Shah, A., & Flahault, A. (2019). Modeling and predicting dengue incidence in highly vulnerable countries using panel data approach. *International Journal of Environmental Research and Public Health*, 16(13), 2296. https://doi.org/10.3390/ijerph16132296

Arcari, P., & Tapper, N. (2017). The variable impact of ENSO events on regional dengue/DHF in Indonesia. *Singapore Journal of Tropical Geography*, 38(1), 5-24. https://doi.org/10.1111/sjtg.12179

Arcari, P., Tapper, N., & Pfueller, S. (2007). Regional variability in relationships between climate and dengue/DHF in Indonesia. *Singapore Journal of Tropical Geography*, 28(3), 251-272. https://doi.org/10.1111/j.1467-9493.2007.00300.x

Arsin, A. A., Istiqamah, S. N. A., Elisafitri, R., Nurdin, M. A., Sirajuddin, S., Pulubuhu, D. A. T., . . . Yani, A. (2020). Correlational study of climate factor, mobility and the incidence of Dengue Hemorrhagic Fever in Kendari, Indonesia. *Enfermeria Clinica*, 30, 280-284. https://doi.org/10.1016/j.enfcli.2020.06.064

Baig, H. Z., & Nawaz, A. J. (2012). Climatic factors affecting dengue fever incidence in Lahore, Pakistan. *Dengue Bulletin*, 36, 64.

Barrera, R., Amador, M., & MacKay, A. J. (2011). Population Dynamics of Aedes aegypti and Dengue as Influenced by Weather and Human Behavior in San Juan, Puerto Rico. *PLoS Neglected Tropical Diseases*, 5(12), e1378. https://doi.org/10.1371/journal.pntd.0001378

Benedum, C.M., Seidahmed, O.M., Eltahir, E.A., & Markuzon, N. (2018). Statistical modeling of the effect of rainfall flushing on dengue transmission in Singapore. *PLoS Neglected Tropical Diseases*, 12(12), e0006935. https://doi.org/10.1371/journal.pntd.0006935

Campbell, K.M. (2014). The complex relationship between weather and dengue virus transmission in Thailand and Peru. *American Journal of Tropical Medicine and Hygiene*, 91(5), 29-430.

Carrington, L.B., Seifert, S.N., Willits, N.H., Lambrechts, L., & Scott, T.W. (2013). Large diurnal temperature fluctuations negatively influence Aedes aegypti (Diptera: Culicidae) life-history traits. *Journal of Medical Entomology,* 50(1), 43-51. https://doi.org/10.1603/ME11242

Center for Disease Control and Prevention. (2021). *Dengue*. Retrieved from https://www.cdc.gov/dengue/index.html

Chaiphongpachara, T., Pimsuka, S., Na Ayudhaya, W. S., & Wassanasompong, W. (2017). The application of geographic information system in dengue haemorrhagic fever risk assessment in samut Songkhram province, Thailand. *International Journal of GEOMATE*, 12(30), 53-60. https://doi.org/10.21660/2017.30.160601

Chandra, G., & Mukherjee, D. (2022). Chapter 35 - Effect of climate change on mosquito population and changing pattern of some diseases transmitted by them. *Advances in Animal Experimentation and Modeling*, 455-460. https://doi.org/10.1016/B978-0-323-90583-1.00030-1

Chandran, R., & Azeez, P.A. (2015). Outbreak of dengue in Tamil Nadu, India. *Current Science*, 109(1), 171-176.

Channa, M.A., & Memon, N. (2020). Seasonal variation in the prevalence of larvae of Aedes aegypti mosquito in district Hyderabad, Sindh, Pakistan. *Pesquisa Agropecuaria Brasileira,* 9(2), 1354-1363. http://dx.doi.org/10.19045/bspab.2020.90142

Costa, E.A.P.d.A., Santos, E.M., Correia, J.C., & Albuquerque, C.M.R.d. (2010). Impact of small variations in temperature and humidity on the reproductive activity and survival of Aedes aegypti (Diptera, Culicidae). *Revista Brasileira De Entomologia*, 54, 488-493. https://doi.org/10.1590/S0085-56262010000300021

De Garín, A. B., Bejarán, R.A., Carbajo, A.E., De Casas, S.C., Schweigmann, N.J. (2000). Atmospheric control of Aedes aegypti populations in Buenos Aires (Argentina) and its variability. *International Journal of Biometeorology,* 44(3), 148-156. https://doi.org/10.1007/s004840000051

Dhimal, M., Gautam, I., Joshi, H. D., O'Hara, R. B., Ahrens, B., & Kuch, U. (2015). Risk Factors for the Presence of Chikungunya and Dengue Vectors (Aedes aegypti and Aedes albopictus), Their Altitudinal Distribution and Climatic Determinants of Their Abundance in Central Nepal. *PLoS Neglected Tropical Diseases*, 9(3). https://doi.org/10.1371/journal.pntd.0003545

Dufault, B., & Klar, N. (2011). The Quality of Modern Cross-Sectional Ecologic Studies: A Bibliometric Review. *American Journal of Epidemiology*, 174(10), 1101-1107. https://doi.org/10.1093/aje/kwr241

Dutta, S., Jagtap, M., Balasubramaniam, R., Kulkarni, N., Danish, M., Deshpande, S., Satpute, U., Wayal, R., Bhagbat, P., Nambier, B., Kulkarni, D., Bile, L., Kamble, P.V., Ghosh, K., Sawaisarje, G.K., Khedikar, S., Patil, C., Sahai, A.K., Alam, O. (2021). A pilot study on assessing the effect of climate on the incidence of vector borne disease at pune and pimpri-chinchwad area, maharashtra. *Mausam*, 72(2), 399-414. https://doi.org/10.54302/mausam.v72i2.611

Ehelepola, N., & Ariyaratne, K. (2015). The interrelationship between dengue incidence and diurnal ranges of temperature and humidity in a Sri Lankan city and its potential applications. *Global Health Action*, 8(1). https://doi.org/10.3402/gha.v8.29359

Ehelepola, N.D., & Ariyaratne, K. (2015). The interrelationship between dengue incidence and diurnal ranges of temperature and humidity in a Sri Lankan city and its potential applications. *Glob Health Action*, 8, 29359. https://doi.org/10.1186/s40249-015-0075-8

Ehelepola, N. D., Ariyaratne, K., Buddhadasa, W. M., Ratnayake, S., & Wickramasinghe, M. (2015). A study of the correlation between dengue and weather in Kandy City, Sri Lanka (2003 -2012) and lessons learned. *Infectious Diseases of Poverty*. https://doi.org/10.1186/s40249-015-0075-8

Fareed, N., Ghaffar, A., & Malik, T.S. (2016). Spatio-temporal extension and spatial analyses of dengue from Rawalpindi, Islamabad and Swat during 2010-2014. *Climate*, 4(2), 23. https://doi.org/10.3390/cli4020023

Garjito, T. A., Hidajat, M. C., Kinansi, R. R., Setyaningsih, R., Anggraeni, Y. M., Mujiyanto, Trapsilowati, W., Jastal, Ristiyanto, Satoto, T.B.T., Gavotte, L., Manguin, S., Frutos, R. (2020). Stegomyia Indices and Risk of Dengue Transmission: A Lack of Correlation. *Frontiers in Public Health*, 8. https://doi.org/10.3389/fpubh.2020.00328

Goto, K., Kumarendran, B., Mettananda, S., Gunasekara, D., Fujii, Y., & Kaneko, S. (2013). Analysis of effects of meteorological factors on dengue incidence in Sri Lanka using time series data. *PLoS One*, 8(5), e63717. https://doi.org/10.1371/journal.pone.0063717

Gubler, D.J. (2011). Dengue, Urbanization and Globalization: The Unholy Trinity of the 21 Century. *Tropical Medicine and Health*, 39, S3-S11. https://doi.org/10.2149/tmh.2011-S05

Harumy, T.H.F., & Ginting, D.S.B. (2021). Neural Network Enhancement Forecast of Dengue Fever Outbreaks in Coastal Region. *Paper presented at the 5th International Conference on Computing and Applied Informatics, ICCAI 2020.* https://doi.org/10.1088/1742-6596/1898/1/012027

Haryanto, B. (2016) Health adaptation scenario and dengue fever vulnerability assessment in Indonesia. *Advances in Asian Human-Environmental Research, Springer International Publishing*, 221-236. https://doi.org/10.1007/978-3-319-23684-1_13

Higa, Y. (2011). Dengue Vectors and their Spatial Distribution. *BMC Tropical Medicine and health,* 39(4) 17-27. https://doi.org/10.2149/tmh.2011-S04

Husnina, Z., Clements, A. C. A., & Wangdi, K. (2019). Forest cover and climate as potential drivers for dengue fever in Sumatra and Kalimantan 2006–2016: a spatiotemporal analysis. *Tropical Medicine and International Health,* 24(7), 888-898. https://doi.org/10.1111/tmi.13248

Intergovernmental panel on Climate Change. (2022). *Climate Change 2021: The Physical Science Basis*.

IOP Conference Series: Earth and Environmental Science. (2018). Paper presented at the 1st International Conference on Tropical Medicine and Infectious Diseases, ICTROMI 2017, in conjunction with the 23rd National Congress of the Indonesian Society of Tropical and Infectious Diseases Consultant, ISTIC 2017 and the 18th Annual Meeting of Internal Medicine Department, Faculty of Medicine, Universitas Sumatera.

Ishak, N.I., & Kasman, K. (2018). The effect of climate factors for dengue hemorrhagic fever in Banjarmasin City, South Kalimantan Province, Indonesia, 2012-2016. *Public Health of Indonesia*, 4(3), 121. https://doi.org/10.36685/phi.v4i3.181

Islam, S., Emdad Haque, C., Hossain, S., & Hanesiak, J. (2021). Climate variability, dengue vector abundance and dengue fever cases in dhaka, bangladesh: A time-series study. *Atmosphere,* 12(7). 905. https://doi.org/10.3390/atmos12070905

Jat, M.K., & Mala, S. (2017). Application of GIS and space-time scan statistic for vector born disease clustering. *Paper presented at the 10th International Conference on Theory and Practice of Electronic Governance, ICEGOV 2017*, 329-338. https://doi.org/10.1145/3047273.3047361

Jaya, I.G.N.M., & Folmer, H. (2021). Identifying Spatiotemporal Clusters by Means of Agglomerative Hierarchical Clustering and Bayesian Regression Analysis with Spatiotemporally Varying Coefficients: Methodology and Application to Dengue Disease in Bandung, Indonesia. *Geographical Analysis*, 53(4), 767-817. https://doi.org/10.1111/gean.12264

Joshua, V., Kaliaperumal, K., Krishnamurthy, K. B., Muthusamy, R., Venkatachalam, R., Gowri, K. A., Shete, V.C., RamasamyMurhekar, S., Gupta, N., Murhekar, M.V. (2020). Exploration of population ecological factors related to the spatial heterogeneity of dengue fever cases diagnosed through a national network of laboratories in India, 2017. *Indian Journal of Medical Research*, 151(1), 79-86. https://doi.org/10.4103%2Fijmr.IJMR_1096_18

Khairunisa, U., Wahyuningsih, N.E., Suhartono, & Hapsari. (2018). Impact of Climate on the incidence of Dengue Haemorrhagic fever in Semarang City. *Paper presented at the 7th International Seminar on New Paradigm and Innovation on Natural Sciences and Its Application, ISNPINSA 2017. https://doi.org/10.1088/1742-6596/1025/1/012079*

Khalid, B., Bueh, C., & Ghaffar, A. (2021). Assessing the Factors of Dengue Transmission in Urban Environments of Pakistan. *Atmosphere*, 12(6), 773. https://doi.org/10.3390/atmos12060773

Khan, S.Y., Tahir, H.M., Ahsan, M.M., Malik, H.T., & Butt, A. (2014). Estimation of adult density of aedes albopictus (Diptera: Culicidae) in some hilly areas of Pakistan. *Pakistan Journal of Zoology*, 46(2), 567-570.

Lambrechts, L., Paaijmans, K.P., Fansiri, T., Carrington L.B., Kramer, L.D., Thomas, M.B., & Scott, T.W. (2011). Impact of daily temperature fluctuations on dengue virus transmission by Aedes aegypti. *roceedings of the National Academy of Sciences of the United States of America*, 108, 7460 - 7465. https://doi.org/10.1073/pnas.1101377108

Liu, Z., Zhang, Z., Lai, Z., Zhou, T., Jia, Z., Gu, J., Wu, K., Chen, X.G. (2017). Temperature Increase Enhances Aedes albopictus Competence to Transmit Dengue Virus. *Frontiers in Microbiology*, 8. https://doi.org/10.3389/fmicb.2017.02337

Lowe, R., Cazelles, B., Paul, R., & Rodó, X. (2016). Quantifying the added value of climate information in a spatio-temporal dengue model. *Stochastic Environmental Research and Risk Assessment,* 30(8), 2067-2078. https://doi.org/10.1007/s00477-015-1053-1

Maulana, M.R., Yudhastuti, R., Lusno, M.F.D., Mirasa, Y.A., Haksama, S., & Husnina, Z. (2021). Dengue fever distribution, climate and visitors: A study from badung District of Bali, Indonesia. *International Journal of Environmental Health Research.* https://doi.org/10.1080/09603123.2022.2065249

Minarti, M., Anwar, C., Irfannuddin, I., Irsan, C., Amin, R., & Ghiffari, A. (2021). Impact of climate variability and incidence on dengue hemorrhagic fever in palembang city, south sumatra, indonesia. *Open Access Macedonian Journal of Medical Sciences,* 9, 952-958. https://doi.org/10.3889/oamjms.2021.6853

Mourad Ouzzani, H.H., Zbys Fedorowicz, Ahmed Elmagarmid. (2016). Rayyan — a web and mobile app for systematic reviews. *Systematic Reviews, https://doi.org/10.1186/s13643-016-0384-4*

Mukhtar, M.U., Mukhtar, M., Iqbal, N., Nawaz, Z., Bhatti, A., Haq, F., Arslan, A., Rashid, M. (2021). The emergence of Dengue Fever in Sheikhupura, Pakistan: Its seroprevalence and risk factors assessment during 2014-2017. *Journal of Infection in Developing Countries*, 15(9), 1351-1355. https://doi.org/10.3855/jidc.13976

Muurlink, O.T., Stephenson, P., Islam, M.Z., & Taylor-Robinson, A. W. (2018). Long-term predictors of dengue outbreaks in Bangladesh: A data mining approach. *Infectious Disease Modelling,* 3, 322-330. https://doi.org/10.1016/j.idm.2018.11.004

Nair, D.G., & Aravind, N.P. (2020). Association between rainfall and the prevalence of clinical cases of dengue in Thiruvananthapuram district, India. *Internation Journal of Mosquito Research*, 46-50. https://doi.org/10.22271/23487941.2020.v7.i6a.488

Nasir, S., Asrar, M., Rasul, A., Hussain, S. M., Aslam, N., Ahmed, F., Yousaf, I., Ashraf, F., Debboun, M. (2018). Potential impact of global warming on population dynamics of dengue mosquito, aedes albopictus skuse (Diptera; culicidae). *Pakistan Journal of Agricultural Sciences*, 55(4), 889-895.

Netrananda, S., & Mani, M.M. (2021). Ramification of global and local climatic variability on resurgent cases of dengue in delhi, india. *Disaster Advances,* 14(7), 32-41. https://doi.org/10.25303/147da3221

Noppradit, P., Pradit, S., Muenhor, D., Doungsuwan, N., Whangsani, U., Sama, N., & Towatana, P. (2021). Investigation of 37 years weather record and its relation to human health: A case study in Songkhla Province, Southern Thailand. *International Journal of Agricultural Technology*, 17(4), 1507-1520.

OECD. (2018). Reproductive biology of the mosquito Ae. *Aegypti*, *in Safety Assessment of Transgenic Organisms in the Environment, Paris: OECD publishing*.

Osuolale, O. A.O. (2023). Precursor to Dengue: Projecting Effects of Climate Change on Mosquito Density in Southeast Asia. *Environmental Health Perspectives*, 131(3), 1552-9924. https://doi.org/10.1289/EHP12772

Ouattara, C. A., Traore, T. I., Traore, S., Sangare, I., Meda, C. Z., & Savadogo, L. G. B. (2022). Climate factors and dengue fever in Burkina Faso from 2017 to 2019. *Journal of public health in Africa*, 13(1). https://doi.org/10.4081/jphia.2022.2145

Pandey, N., Nagar, R., Gupta, S., Khan, D., Singh, D. D., Mishra, G., Prakash, S., Singh, K.P., Singh M., Jain, A. (2012). Trend of dengue virus infection at Lucknow, north India (2008- 2010): a hospital based study. *Indian Journal of Medical Research,* 136(5), 862-867.

Paul, K.K., Dhar-Chowdhury, P., Haque, C. E., Al-Amin, H. M., Goswami, D. R., Kafi, M.A.H., Michael A.D., L. Robbin L., Gias U.A., Brooks, W.A. (2018). Risk factors for the presence of dengue vector mosquitoes, and determinants of their prevalence and larval site selection in Dhaka, Bangladesh. *PLoS One*, 13(6), e0199457. https://doi.org/10.1371/journal.pone.0199457

Peña-García, V.H., Triana-Chávez, O., & Arboleda-Sánchez, S. (2017). Estimating Effects of Temperature on Dengue Transmission in Colombian Cities. *Annals of Global Health*, 83(3), 509-518. http://doi.org/10.1016/j.aogh.2017.10.011

Pichainarong, N., Mongkalangoon, N., Kalayanarooj, S., & Chaveepojnkamjorn, W. (2006). Relationship between body size and severity of dengue hemorrhagic fever among children aged 0-14 years. *Southeast Asian J Trop Med Public Health*, 37(2), 283-288.

Polwiang, S. (2016). The correlation of climate factors on dengue transmission in urban area: Bangkok and Singapore cases. *PeerJ Preprints*, 4, e2322v2321.

Qureshi, E.M.A., Tabinda, A.B., & Vehra, S. (2017). The distribution of Aedes aegypti (Diptera, culicidae) in eight selected parks of Lahore, using oviposition traps during rainy season. *Journal of the Pakistan Medical Association*, 67(10), 1493-1497.

Rahman, K.M., Sharker, Y., Rumi, R.A., Khan, M.I., Shomik, M.S., Rahman, M.W., Billah Sk M., Rahman, M., Streatfield, P.K., Harley, D., Luby, S.P. (2020). An Association between Rainy Days with Clinical Dengue Fever in Dhaka, Bangladesh: Findings from a Hospital Based Study. *International Journal of Environmental Research and Public Health,* 17(24). https://doi.org/10.3390/ijerph17249506

Rahman, M., Ekalaksananan, T., Zafar, S., Poolphol, P., Shipin, O., Haque, U., Paul, R., Rocklov J., Pientong C., Overgaard, H.J. (2021). Ecological, social, and other environmental determinants of dengue vector abundance in urban and rural areas of northeastern Thailand. *International Journal of Environmental Research and Public Health,* 18(11), 5971. https://doi.org/10.3390/ijerph18115971

Rahman, S.A., Rahim, A., & Mallongi, A. (2018). Risk analysis of dengue fever occurrence in bone province sulawesi south using temporal spatial geostatistical model. Indian Journal of Public Health Research and Development, 9(4), 221-226. https://doi.org/10.5958/0976-5506.2018.00287.5

Ratnasari, A., Jabal, A. R., Rahma, N., Rahmi, S. N., Karmila, M., & Wahid, I. (2020). The ecology of aedes aegypti and aedes albopictus larvae habitat in coastal areas of South Sulawesi, Indonesia. *Biodiversitas,* 21(10), 4648-4654. https://doi.org/10.13057/biodiv/d211025

Riyanto, I.A., Susianti, N.A., Sholihah, R.A., Pradipta Rizki, R.L., Cahyadi, A., Naufal, M., Ramadhan, F., Ramadan. V.K., Risky, A.S. (2020). The spatiotemporal analysis of dengue fever in Purwosari district, Gunungkidul Regency, Indonesia. *Indonesian Journal of Geography*, 52(1), 80-91. https://doi.org/10.22146/ijg.49366

Roy, M.P., Gupta, R., Chopra, N., Meena, S.K., & Aggarwal, K.C. (2018). Seasonal Variation and Dengue Burden in Paediatric Patients in New Delhi. *Journal of Tropical Pediatrics*, 64(4), 336-341. https://doi.org/10.1093/tropej/fmx077

Rueda, L.M., Patel, K., Axtell, R.C., & Stinner, R.E. (1990). Temperature-dependent development and survival rates of Culex quinquefasciatus and Aedes aegypti (Diptera: Culicidae). *Journal of Medical Entomology,* 27, 892 - 898. https://doi.org/10.1093/jmedent/27.5.892

Rusli, Y., & Yushananta, P. (2020). Climate variability and dengue hemorrhagic fever in Bandar Lampung, Lampung Province, Indonesia. *International Journal of Innovation, Creativity and Change*, 13(2), 323-336.

Sahay, S. (2018). Climatic variability and dengue risk in urban environment of Delhi (India). *Urban Climate,* 24, 863-874. https://doi.org/10.1016/j.uclim.2017.10.008

Salam, N. (2018). Analysis of the Effects of Rainfall on Dengue Incidence in the City of Delhi, India. *International Journal of Medical Research & Health Sciences*, 7(12), 149-155. https://doi.org/10.1101/423517 d

Salamah, M., Kuswanto, H., & Yussanti, N. (2012). On the influence of climate and socio-economic condition to the dengue incidences: A semiparametric panel regression approach. *American Journal of Environmental Sciences*, 8(6), 661-667. https://doi.org/10.3844/ajessp.2012.661.667

Salim, M.F., & Syairaji, M. (2020). Time-Series Analysis of Climate Change Effect on Increasing of Dengue Hemorrhagic Fever (DHF) Case with Geographic Information System Approach in Yogyakarta, Indonesia. *International Proceedings The 2nd ISMoHIM 2020*.

Scott, T.W., Morrison, A.C., Lorenz, L.H., L Clark, G.G., Strickman, D., Kittayapong, P., Zhou, H., & Edman, J.D. (2000). Longitudinal studies of Aedes aegypti (Diptera: Culicidae) in Thailand and Puerto Rico: population dynamics. *Journal of Medical Entomology*, 37, 77-88. https://doi.org/10.1603/0022-2585-37.1.77

Seah, A., Aik, J., Ng, L.C., & Tam, C.C. (2021). The effects of maximum ambient temperature and heatwaves on dengue infections in the tropical city-state of Singapore – A time series analysis. *Science of the Total Environment*, 775. https://doi.org/10.1016/j.scitotenv.2021.145117

Shashvat, K., Basu, R., & Bhondekar, A. P. (2021). Application of time series methods for dengue cases in North India (Chandigarh). *Journal of Public Health (Germany),* 29(2), 433-441. https://doi.org/10.1007/s10389-019-01136-7

Silva, F.D., dos Santos, A.M., Corrêa Rda, G., & Caldas Ade, J. (2016). Temporal relationship between rainfall, temperature and occurrence of dengue cases in São Luís, Maranhão, Brazil. *Ciencia & saude coletiva*, 21, 641-646. https://doi.org/10.1590/1413-81232015212.09592015

Sriklin, T., Kajornkasirat, S., & Puttinaovarat, S. (2021). Dengue transmission mapping with weather-based predictive model in three southernmost provinces of thailand. *Sustainability (Switzerland),* 13(12). https://doi.org/10.3390/su13126754

Sripugdee, S., Inmoung, Y., & Junggoth, R. (2010). Impact of climate change on dengue hemorrhagic fever epidemics. *Research Journal of Applied Sciences*, 5(4), 260-262. https://doi.org/10.3923/rjasci.2010.260.262

Supadmi, W., Perwitasari, D.A., Abdulah, R., & Suwantika, A.A. (2019). Correlation of rainfall and socio-economic with incidence dengue in Jakarta, Indonesia. *Journal of Advanced Pharmacy Education and Research,* 9(1), 134-142.

The EndNote Team. (2013). EndNote (Version EndNote 20) [64 bit]. *Clavirate,* Philadelphia.

The Joanna Briggs Institute. (2015). The Joanna Briggs Institute. *Joanna Briggs Institute.*

Tosepu, R., Tantrakarnapa, K., Worakhunpiset, S., & Nakhapakorn, K. (2018). Climatic factors influencing dengue hemorrhagic fever in Kolaka district, Indonesia. *Environment and Natural Resources Journal,* 16(2), 1-10.

United States Environmental Protection Agency. (2022, 2022, August 1st). *Climate change indicators*.

Watts, D.M., Burke, D.S., Harrison, B.A., Whitmire, R.E., & Nisalak, A. (1987). Effect of temperature on the vector efficiency of Aedes aegypti for dengue 2 virus. *The American Journal of Tropical Medicine and Hygiene,* 36(1), 143-152. https://doi.org/10.4269/ajtmh.1987.36.143

Wijegunawardana, N., Gunawardene, Y., Chandrasena, T., Dassanayake, R.S., Udayanga, N., & Abeyewickreme, W. (2019). Evaluation of the Effects of Aedes Vector Indices and Climatic Factors on Dengue Incidence in Gampaha District, Sri Lanka. *BioMed research International*, 2019. https://doi.org/10.1155/2019/2950216

Wongkoon, S., Jaroensutasinee, M., & Jaroensutasinee, K. (2012). A forecasting system for dengue fever in Nakhon Si Thammarat, Thailand. *International Journal of Infectious Diseases*, 16, e365. https://doi.org/10.1016/j.ijid.2012.05.460

Wongkoon, S., Jaroensutasinee, M., & Jaroensutasinee, K. (2013). Distribution, seasonal variation & dengue transmission prediction in Sisaket, Thailand. *The Indian Journal of Medical Research*, 138(3), 347.

World Health Organization. (2022a). Dengue and severe dengue. *World Health Organization.*

World Health Organization. (2022b). Dengue in South-East Asia. *World Health Organization.*

World Meteorological Organizaton. (2022). State of the Global Climate 2021 (WMO - No 1290). *World Meteorological Organizaton*.

Xu, L., Stige, L.C., Chan, K.S., Zhou, J., Yang, J., Sang, S., Wang, M., Yang, Z., Yan, Z., Jiang, T., Lu. L., Yue, Y., Liu, X., Lin, H., Xu, J., Liu, Q., Stenseth, N.C. (2017). Climate variation drives dengue dynamics. *Proceedings of the National Academy of Sciences*, 114(1), 113-118. https://doi.org/10.1073/pnas.1618558114

Zahirul Islam, M., Rutherford, S., Phung, D., Uzzaman, M. N., Baum, S., Huda, M. M., Asaduzzaman, M., Talukder, M.R.R., Chu, C. (2018). Correlates of Climate Variability and Dengue Fever in Two Metropolitan Cities in Bangladesh. *Cureus,* 10(10), e3398. https://doi.org/10.7759/cureus.3398

Zamli, Syafar, M., Palutturi, S., Suriah, Arsin, A. A., Hatta, & Amiruddin, R. (2019). Potential of rainfall, humidity and temperature, against the increasing of larvae in makassar city, Indonesia. *International Journal of Innovative Technology and Exploring Engineering*, 9(1), 1485-1487. http://doi.org/10.35940/ijitee.A4296.119119

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