REVIEW ARTICLE

Implication of heat islands on dengue incidence in urban areas: a systematic review

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ABSTRACT

An urban heat island is known to adversely affect the microclimate in an area, which includes temperature, rainfall, relative humidity, and wind velocity. These climatic changes may influence the transmission of dengue and density of *Aedes* mosquitoes due to their effect on the life cycle of *Aedes* mosquitoes, which is the primary vector for dengue. This review aims to analyse existing literature on urban heat islands and their implication on dengue incidence. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used as a reference to review resources from three databases, which were Scopus, Web of Sciences (WoS), and ScienceDirect. From the keyword search, 212 articles published between 2003 and 2022 were identified, but only 123 articles were included in the screening phase. Upon applying the review criteria, 39 articles were sought for retrieval; however, only 36 of them were assessed for eligibility following the unsuccessful retrieval of three (3) articles. In total, 12 articles were included in the review after the eligibility and quality appraisal. Analysis of the articles was performed by reading the full articles and extracting the information on study location, year of publication, variables, and findings. It was found that urban heat islands can be described as areas with high temperatures, low vegetation coverage, and a high percentage of built-up areas, which can be associated with high dengue incidences. Additionally, it was learned that the higher temperatures in urban areas have influence on dengue transmission and may contribute an increase in the *Aedes* mosquito density. In conclusion, even though the urban heat island phenomenon itself may not be directly associated with dengue transmission and *Aedes* density, the higher temperatures in the cities induced by the heat islands have shown evidence of association to dengue transmission, which affects the *Aedes* mosquito density. It is suggested that more in-depth studies are needed to determine the implications of urban heat islands on dengue incidence. Such studies are required, particularly when employing indicators such as urban heat island intensity, daytime and nighttime temperatures, population density, and socio-economic characteristics as research variables, with a focus on urban cities with higher risk of dengue transmission.

Key words:
heat islands, temperature, dengue, *Aedes*, urban area, PRISMA

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INTRODUCTION

Rapid expansion of urban areas and the development of various infrastructures have caused many urban areas to suffer urban heat island (UHI) effects.[1] Currently, more than half of the population in the world live in cities and are exposed to these heat islands.[2,3] The UHI phenomenon was first studied as a scientific field of meteorology and climatology on urban atmosphere in the early 19th century before the gradual discovery of the"city temperature effect" or heat island effect, which is now more centralised in the urban climatology field.[4] Population growth in combined with urbanisation may increase the duration and intensity of urban heat islands in urban areas.[3,5,6] Urbanisation causes changes in urban morphology and urban physical properties, all of which affect microclimate parameters that give rise to the UHI phenomenon.[6] Urban microclimate, land use, and land cover are crucial elements that influence the dynamic of mosquito population and disease transmission, such as the trend of dengue fever in urban areas.[7]

World Health Organisation (WHO) has stated that as of 30 April 2024, there have been over 7.6 million dengue cases reported to WHO, with 3.4 million confirmed cases.[8] One of the risk factors for this transmission is the rising temperatures, which favour vector reproduction and virus transmission.[8] Dengue fever is caused by the dengue virus which is transmitted through the bites of infected *Aedes* mosquitoes. In Malaysia, the primary vector for dengue transmission is *Aedes aegypti*, while *Aedes albopictus* acts as a secondary vector for the disease; both can be found in tropical and subtropical regions.[9,10,11] These mosquitoes are sensitive to temperature due to their poikilotherms characteristics in which their body temperature is not constant and requires various strategies to reduce risk of thermal stress.[12] Thus, climate factors play important roles in the behaviour and viability of the *Aedes* spp.[13] A study found that throughout the life cycle of *Aedes aegypti*, the mosquitoes can survive in any temperature; however, they are susceptible to higher temperatures (39°C–40°C), which suppress the *Aedes* embryonic development and cause larval death within several hours without hatching. This results in smaller mosquito size and low larval density, as well as a shorter development time to adulthood.[10,11,14]

The burden of the dengue disease has increased over the last half of the century due to several factors, such as global travelling and trade, population growth, urbanisation and climate changes.[15] It has been noted that factors such as temperature, humidity and rainfall are associated with dengue, where it has been reported that temperature rises lead to the spread of vector-borne diseases, such as dengue, in urban areas.[8,16] On the other hand, the full effects of urban heat islands, which are associated with increased temperatures in urban areas, on dengue have yet to be fully understood. As such, this review aims to determine the implications of urban heat islands on dengue incidence to establish further understanding of the association between the heat islands, dengue, and *Aedes* mosquitoes while exploring the factors that contribute to this association, such as increase in temperature, other climatic factors, land use, and land cover of the cities. Moreover, urban heat islands may have influences on the dengue vectors, such as *Aedes aegypti* by providing suitable conditions for its life cycle development and survivability, leading to favourable condition for the mosquitoes in the urban areas.[17] This review will be beneficial to health and local authorities in providing knowledge on the factors that can contribute to the dengue transmission in urban areas. Consequently, this will allow for proper planning and implementation of mitigating measures, not only to control the dengue transmission but also to allow for better design of urban planning and development that can prevent potential breeding sites for the dengue vector in the urban areas.

METHODS

This review was done using PRISMA guidelines which consist of methods for the resources, eligibility, inclusion and exclusion criteria, systematic review process, extraction, and analysis of data on the existing literature.[18] The PRISMA 2020 statement had replaced the 2009 statement, which included a new reporting guide reflecting advanced identification, selection, appraisal, and synthesis study methods.[19] The PRISMA statement allows for rigorous term searches related to the review while suggesting standard items to be considered when reporting a review for publication.[20] Several inclusion and exclusion criteria were determined for the review, which included literature type (article journal only) and English language articles to avoid confusion in the translation of the aforementioned articles.[18] The timeline selected for the review was a period of 20 years, which is from 2003 to 2022, to allow the inclusion of more research in the review. Only open-access articles were retrieved for the screening process.

This review involves three databases (Scopus, Web of Science, and ScienceDirect). Identification of articles is done using a combination of keywords using Boolean operator(s) AND and/or OR. Similar keywords related to urban heat islands, dengue incidence, and *Aedes* mosquitoes were used to widen the search scope. Table 1 shows the keyword string used for the literature search.

Table 1. Keywords string for literature search

Databases	Keywords used
Scopus	TITLE-ABS-KEY("urban heat island*" OR "heat island*" OR "heat island effect*" OR "extreme weather*" OR "extreme climate*" OR "surface heat island*" OR "atmospheric heat island*" OR "microclimate*") AND ("urbanization" OR "urbanisation" OR "urbanized" OR "urban") AND ("dengue" OR "dengue fever" OR "dengue incidence*" OR "dengue occurrence*" OR "dengue case*" OR "dengue outbreak*" OR "dengue prevalence" OR "dengue transmission*" OR "dengue infection*") AND ("Aedes" or "Aedes mosquito*" OR "Aedes aegypti" OR "Aedes albopictus") AND ("urban city*" OR "urban area*" OR "urban settings" OR "cities" OR "city")
Web of Science	TS=(("urban heat island*" OR "heat island*" OR "heat island effect*" OR "extreme weather*" OR "extreme climate*" OR "surface heat island*" OR "atmospheric heat island*" OR "microclimate*") AND ("urbanization" OR "urbanisation" OR "urbanized" OR "urban") AND ("dengue" OR "dengue fever" OR "dengue incidence*" OR "dengue occurrence*" OR "dengue case*" OR "dengue outbreak*" OR "dengue prevalence" OR "dengue transmission*" OR "dengue infection*") AND ("Aedes" or "Aedes mosquito*" OR "Aedes aegypti" OR "Aedes albopictus") AND ("urban city*" OR "urban area*" OR "urban settings" OR "cities" OR "city"))

Databases	Keywords used
ScienceDirect	("urban heat island" OR "heat island") AND ("dengue" OR "dengue incidence" OR "dengue outbreak" OR "dengue prevalence" OR "dengue transmission") AND ("Aedes" OR "Aedes mosquito")

Duplication of similar articles was carefully screened and removed. Screening of articles was conducted independently by two reviewers using the inclusion and exclusion criteria to ensure the eligibility of the articles for the review. Reviewers can manually include and exclude an article by reading the titles, abstracts, and if necessary, the result section. All articles that have passed this stage were retrieved before quality appraisal was performed on each article. Quality appraisal involved providing a quality score to each article by two reviewers and categorizing them into excellent, good, fair, or fail. Any disagreement on the categorisation of each article between reviewers was discussed to achieve a final agreement. Those articles under the category of fail were removed from the review. Articles that have undergone screening and passed quality appraisal with scores of fair, good, and excellent were included in the review.

Data on study location, year of publication, variables, and findings were obtained and extracted by reading the full articles. No themes were used for this review and the main objective of this review was to determine the implications of urban heat islands on dengue incidences in urban areas. This review also included articles that focus on *Aedes* mosquitoes instead of dengue incidence, as the mosquitoes are vectors for the dengue virus.

RESULTS

Based on the findings, it was found that limited literature has been published in regard to the implications of urban heat islands on dengue incidences. Using a keyword string in three databases (Scopus, Web of Science and ScienceDirect), 212 articles have been identified to be included in this review but only 12 were successfully included in this review after screening, eligibility and appraisal were performed on the identified journals. Figure 1 shows the systematic review flow. All included articles in this review were given specific identification (ID) either beginning with an A (*Aedes*) or a D (dengue) to indicate the dependent variables of the studies. Dependent variables of each article were determined during the review to identify the variables to be observed as the outcomes of the study. It was found that the desirable outcome or interest of the articles was mainly focused on dengue transmission or its vector (*Aedes*) density in the urban areas characterised by their interaction with the surrounding temperature, climatic factors, land use/land cover variables, and other factors.

This review included articles that examined *Aedes* mosquitoes' abundance or density in relation to urban heat islands or temperature in urban areas, as *Aedes* mosquitoes are the carriers of the dengue viruses that are responsible for dengue fever. Five articles (D1, D3, D6, A3, and A5) included urban heat islands as variables in their study, while the remaining seven articles (D2, D4, D5, D7, A1, A2, and A4) measured temperature, as it may be an indicator for urban heat islands in the urban areas. Moreover, several articles have included other parameters, such as precipitation/rainfall, wind speed, and relative humidity, among others, which influence the microclimate and urban heat islands in urban areas. All articles included in this study were those that conducted research in city areas to represent the heat island or temperature in the urban areas. Table 2 shows the summary of the reviewed articles.

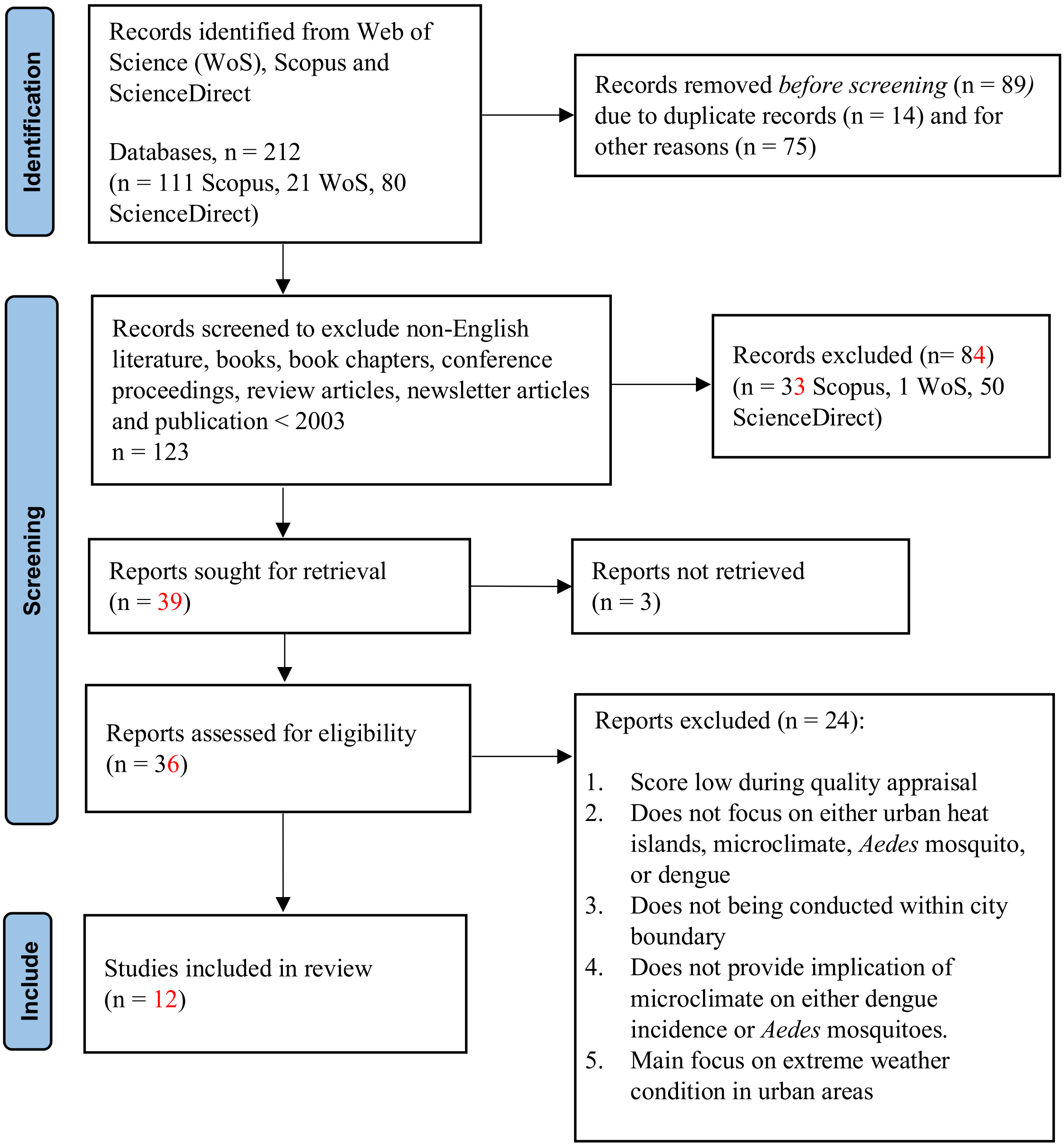

Figure 1. Systematic Review Flow

In general, temperature in urban areas can be associated with dengue incidences and *Aedes* mosquito abundance, where it was found that D1 described the heat islands areas as the areas with a high percentage of built-up areas, low vegetation coverage and high temperatures, which were associated with high dengue incidences. Similarly, D6 also found that the dengue incidence rate was high in low vegetation cover areas reflecting urban areas which further analysis found that more dengue cases clustered in areas with a land surface temperature above 32°C. Besides that, D3 reported a higher urban heat island intensity (UHII) in Bangkok, Thailand, in the inner city, which is considered as an urban area, with an average dengue incidence rate of dengue 131 per 100,000 populations. This indicates that cities or urban areas with higher temperatures influence the increased dengue incidence and transmission.

Moreover, temperature can be also associated with the density and abundance of the *Aedes* mosquitoes in urban areas. A1 has found that *Aedes albopictus* is more abundant in urban and suburban areas with higher temperatures compared to that in rural areas. Meanwhile, A2 contradicted the findings in A1 and reported that warmer climates and less humidity in urban areas are causing decreased larval survival, smaller mosquito body sizes, and lower per capita growth rates of mosquitoes in urban sites. This is also observed in a study by D7, which found a negative correlation between dengue incidence and a diurnal temperature range of more than 7.5°C during an eight-week lag period, and a positive correlation between dengue incidence and a diurnal temperature range of less than 7.5°C, also at an eight-week lag period. This indicates that the temperature in urban areas can influence dengue incidence and *Aedes* mosquitoes' survival and viability.

Table 2. Summary of reviewed articles

ID	Authors	Study Location	Year of Publication	Variables	Findings
D1	Santos et al.[21]	Rio de Janeiro, Brazil	2020	i 17 indicators based on social and environmental determinants of dengue; ii Annual dengue cases; iii Dengue incidence rate; and iv *Aedes* egg density index.	Heat island in this study represents area with high percentage of built-up area, low vegetation coverage and high temperature. Heat islands has been found to correlates with year of dengue incidences in which one of the years was an epidemic year for the city.
A1	Westby et al.[22]	Saint Louis City and its surrounding suburban and rural areas, USA	2021	i *Aedes albopictus* mosquito abundance; ii Breeding water pH, level of evaporation, and total tannins and nitrogen; iii Daily mean humidity; and iv Daily mean temperature.	*Aedes albopictus* more abundant in urban and suburban area. Daily mean temperatures and highest humidity were reported higher in urban areas compared to rural and suburban areas but these differences in microclimate across the seasons may not be large enough to affect the growth rates of the mosquitoes.
D2	Méndez-Lázaro et al.[23]	San Juan, Puerto Rico	2014	i Daily dengue cases; ii Daily rainfall and wind speed; iii Daily Air surface temperature (AST), sea level pressure (SLP), and mean sea level (MSL); iv Monthly sea surface temperature (SST); v Derived 7 indices based on temperature; and vi Derived 6 indices based on rainfall.	Dengue shows seasonal periodicity where pre-epidemic occurs between February to May (dengue cases rise with the increase of air and ocean temperatures and abundant precipitation) before epidemic between June to October. Correlation found between dengue cases with SST, AST, rainfall, MSL and SLP. There is correlation between dengue with the rainfall and changes in minimum air surface temperature.

ID	Authors	Study Location	Year of Publication	Variables	Findings
D3	Nakhapakorn et al.[24]	Bangkok, Thailand	2020	i Monthly dengue data; ii Dengue incidence rate; iii Land surface temperature (LST); and iv Urban heat island intensity.	Average dengue incidence rates were 131 and 124 per 100,000 populations in inner zone and urban fringe in 2009 and 2014. UHII between the inner city and suburban areas was greater than with the UHII between the urban fringe and suburban areas. Building more than 8 floor and average LST have positive correlation with dengue incidence in 2009 and 2014
D4	Cheng et al.[25]	Guandong, China	2020	i Daily dengue data; ii Daily mean temperature from iii Daily mean rainfall; iv Economic factor; v Population density; vi Normalised Difference Vegetation Index (NDVI); and vii Elevation.	Average temperature, temperature variation, and average rainfall were positively associated with dengue incidence, but the associations were not statistically significant. High spatial variability in the risk of dengue occurrence was observed in the centre and east of Guangdong province.
A2	Murdock et al.[26]	Athens-Clarke County, Georgia, USA	2017	i Temperature (average, minimum, and maximum); ii Relative humidity (average, minimum, and maximum); iii Wing length; iv Daily total number of adult mosquito emergence; v Sex of emerged adult mosquito; and vi Per capita mosquito population growth rates.	Warmer temperature cause decreased larval survival, smaller body sizes, and lower per capita growth rates of mosquitoes in urban sites. Dengue transmission potential was predicted to be higher in the summer than the fall. The effects of land use on dengue transmission potential varied by season. Warm summers resulted in a higher predicted vectorial capacity on the cooler, rural sites, while urban sites had a higher predicted vectorial capacity during the cooler fall season.

ID	Authors	Study Location	Year of Publication	Variables	Findings
A3	de Jesús Crespo & Rogers[27]	New Orleans, Louisiana, USA	2021	i Larvae species; ii Temperature; iii Rainfall; iv UHI characterisation, vegetation cover, and median income; and v Water temperature for positive larvae container.	UHI positively correlate to *Aedes aegypti*. *Aedes aegypti* was more often found under the canopy of trees in high heat cemeteries. Whereas *Aedes albopictus* was most often found in low heat cemeteries. Findings found that UHI at the cemetery scale was highly predictive of *Aedes aegypti* and strongly correlated to income level, with low-income cemeteries having higher UHI levels.
D5	Li et al.[28]	Guangzhou, China	2021	i Dengue cases; ii Monthly mean temperature, precipitation, and relative humidity; and iii Socio-ecological variables, e.g., population characteristics, population mobility, urbanisation, and vector habitat.	Temperature plays an important role in the long-time series of dengue transmission, while socio-ecological factors have great explanatory power for dengue outbreaks. The interactions of pairs of climate and socio-ecological factors have more significant impact on dengue where it shows that increasing temperature and surge in travel could cause dengue outbreaks in the future.
A4	Evans et al.[29]	Athens-Clarke County, Georgia, USA	2019	i Larvae and *Aedes albopictus* mosquito abundance; ii Average temperature; iii Average relative humidity; and iv Land class.	The density of positive *Aedes albopictus* larval habitat increased with increasing min, mean, and max temperatures while the larval habitat increased with increasing min relative humidity until approximately 60% relative humidity before higher relative humidity associated with fewer larval habitats.
D6	Araujo et al.[30]	São Paulo, Brazil	2015	i Dengue cases between 2010 and 2011;	The dengue incidence rate was high in low vegetation cover areas where the land surface temperature was 29°C ± 2°C. More dengue cases

ID	Authors	Study Location	Year of Publication	Variables	Findings
				ii Land surface temperature (LST); iii Population data; iv Dengue incidence rate; v Socio-economic status, housing standards; and vi Vegetation cover.	clustered in areas of land surface temperature above 32°C compared to low socio-economic zones, high population density areas, or slum-like areas. *Aedes aegypti* larval development, blood feeding, and oviposition associated positively within the temperatures of 28°C–32°C.
D7	Ehelepola et al.[31]	Colombo District, Sri Lanka	2016	i Dengue incidence; and ii Daily minimum and maximum temperatures.	A negative correlation between dengue incidence and a diurnal temperature range of more than 7.5°C with an eight-week lag period, and a positive correlation between dengue incidence and a diurnal temperature range less than 7.5°C, also with an eight-week lag found in Colombo district.
A5	de Azevedo et al.[17]	Santa Bárbara d'Oeste, Sao Paolo, Brazil	2018	i *Aedes aegypti* abundance; ii Larvae identification; and iii Surface temperature.	Abundant *Aedes aegypti* larval habitats in areas of higher surface temperature and social vulnerability and fewer larval habitats in areas with lower surface temperature and social vulnerability.

*ID of the articles were based on the dependent variable of the studies (D = Dengue, A= *Aedes*)

Furthermore, D3 and D6 supported the findings in A1 and revealed that dengue transmits faster in areas with higher land surface temperatures, while A3 and A5 found that higher temperatures have an impact on the *Aedes* mosquitoes' density. A5 found that there were abundant *Aedes aegypti* larval habitats in areas of higher surface temperature within the urban area and A3 found that *Aedes aegypti* was more often found under the canopy of trees in high heat areas compared to *Aedes albopictus,* which was most often found in low heat areas indicating the preference of *Aedes* mosquitoes breeding habitat. A2 reported that warmer, urban sites had a higher predicted vectorial capacity during the cooler fall season indicating the impact of seasonal periodicity on the dengue epidemic with correlations found between dengue incidence and rainfall as well as changes in minimum air surface temperature.

Lastly, temperature in urban areas has been also associated with dengue incidences as seen in D4 where average temperature and temperature variation were positively associated with dengue incidence. Meanwhile, D5 found that temperature plays an important role in the long-time series of dengue transmission, while socio-ecological factors have significant explanatory power for dengue outbreaks where a surge in travel could cause dengue outbreaks in the future.

DISCUSSION

In understanding the dengue distribution in urban areas, it must be understood that the definition of urban areas may differ from one country to another with some using qualitative criteria while others using quantitative criteria for urban area definition. This review has included articles from studies performed in countries such as the United States of America (USA), Brazil, China, Thailand, Puerto Rico and Sri Lanka, which have different definitions of urban areas. In the United States, an urban area is defined as a territory that consists of at least 2000 housing units or has a population of at least 5000 people.[32] In Brazil, an urban area is identified as an area located within the boundary of a city or town as defined by the municipal law, while China defined urban areas based on their Regulation on the Classification of Urban/Rural Residence for Statistical Purposes.[33] In addition, Thailand classifies its urban areas based on municipalities, while Sri Lanka defines urban areas based on its administered municipal and urban councils. Meanwhile, Puerto Rico identifies the urban areas as agglomerations of 2500 or more inhabitants with population densities of 1000 persons per square mile or more.[33] This allocation of the urban areas may affect the variation in dengue incidences due to differences in the size of urbanised areas, which may affect the incidence rate among the population due to the varying total population in those countries. It can also be assumed that the size of the urban areas may also influence the intensity of urban heat islands (UHI) in urban areas based on their degree of urbanisation, land use, vegetation covers and other factors, which can affect the local microclimate and influence the lifecycle of *Aedes* mosquito.

With the increase in urbanisation and the trend of global warming, temperatures around various areas in the world are expected to increase and influence the trend of dengue transmission.[34] Recently, it was reported that over 10 million dengue cases have been reported from 80 countries/territories in the region of the Americas since the beginning of 2024, with more than 9 million cases of dengue reported and Brazil alone accounted for almost 8 million dengue cases.[35,36] In Asia region, since the beginning of 2024, there has been a downward trend in dengue cases in several countries such as Sri Lanka, Bangladesh and Thailand compared to last year, while in Mainland Europe imported cases of dengue from endemic areas have been found in Germany, Italy and France in 2024.[35] This indicates the public health concerns over dengue transmission around the world due to the high number of cases reported globally, the chances of transmission to new areas due to travelling and increase in urbanisation, as well as climatic factors that may provide a suitable environment for dengue vectors to proliferate and survive.

Although rarely associated directly with dengue incidences, UHI has been known to cause higher temperatures in urban areas that are frequently linked to dengue and *Aedes* abundance. The leading causes of UHI include urbanisation, urban sprawl, and population growth.[37] At the same time, urbanisation has induced mosquito breeding environments leading to an increased risk of dengue infection in urban areas.[38] Large and warmer cities have caused the spread of dengue in which it was found that dengue spread from metropolitan areas towards medium and small cities causing dengue outbreaks in those areas.[39] Moreover, a study has found that higher temperatures, relative humidity, and precipitation cause faster transmission of dengue in urban areas with heat islands, thus revealing a positive impact on the spatial distribution of *Aedes aegypti* habitats.[40]

Currently, there are limited studies that evaluated the implications of UHI on dengue incidences; instead, they are focused mainly on the effect of temperature on the disease. Besides that, it was found that the public health impact of UHI has neglected the context of infectious diseases even though for dengue, temperature changes can have a significant impact on the epidemic potential.[41] Based on these reviews only five articles were found to directly relate UHI to dengue, while the remaining seven articles measured temperature and other environmental variables that can provide indication of heat islands in the urban areas. Nonetheless, these environmental variables also play important roles in the mosquito development phase and abundance at its breeding and resting locations.[42,43]

Many studies have found that temperature plays a significant role in dengue transmission by affecting mosquitoes and their life cycle.[10,40,43] A study has been done to observe the effects of temperature on the vector life cycle, where it found that the generation time for dengue transmission was sensitive to temperature, suggesting the intensification of dengue epidemics as the temperature increases.[44] Moreover, an increase in temperature to 33°C may shorten the development period of *Aedes* mosquitoes in terms of the number of days, which refers to the completion and survival of *Aedes Aegypti* and *Aedes albopictus* from the aquatic life cycle into adult phase.[45] Additionally, it was reported that 52% and 27% of previous studies focus on the effect of temperature on the development and survival of *Aedes* mosquitoes, respectively.[46]

This review also found studies that have included factors such as precipitation, relative humidity, land use, land cover and vegetation cover that correlate with dengue incidence or *Aedes albopictus*. Precipitation and humidity were found to be associated with dengue cases, as precipitation plays an important role in the juvenile stage of the *Aedes* mosquito, while relative humidity prevents mosquitoes and their habitat from drying up.[47] Moreover, in low humidity, the fluid in the adult *Aedes* mosquitoes can evaporate and cause death due to the absence of a regulatory mechanism, as the spiracle on the adult mosquito is always widely open.[47] It can be assumed that even though temperature is an important factor in dengue transmission, *Aedes* mosquitoes can be also influenced by other climatic conditions and various land-use and land cover types.[48,49] A study reported that there is global evidence supporting the land use/land cover (LULC) changes may have an impact on vectors for dengue with transmission of dengue involving a complex interplay of multiple factors such as meteorological variables, air pollutants, demographic characteristics, and socio-economic status.[50]

Normalised Difference Vegetation Index (NDVI) has also been correlated with dengue incidence rate, where NDVI is the indicator for vegetation in one area and can be used to analyse changes in land use for the areas overtime.[51] Similar variables such as LULC and NDVI have also been used to determine the urban heat island effect in an area, where a study found that using LULC and NDVI to determine urban expansion in Sharqiyah Governorate showed the increase in built-up areas by 18.9% and led to land surface temperature increase by 3.98°C with a UHI threshold of 4.27°C.[52] This is because LULC and NDVI are common variables measured in the determination of UHI, thus, it can be assumed that it can affect the UHI and indirectly influence the dengue incidence. LULC, NDVI and land classes (e.g., urban, rural, suburban) indicate urbanisation and associated concretisation that led to an increase in temperature in urban areas and resulted in the occurrence of UHI.[53] On the other hand, UHI and temperature changes have been known to influence dengue transmission and *Aedes* mosquitoes in urban areas.[10,11,39,45,54]

It was found that there are limited articles found in regard to the direct relationship between urban heat islands and dengue transmission and its disease vector. Due to that in some articles, the relationship between UHI and dengue incidence or *Aedes* mosquitoes was not extensively discussed. Regardless of the limited number of articles, this review found a relationship between UHI and increased dengue incidence in areas with higher temperatures and lesser vegetation, and in addition some articles mentioned the influence of precipitation, relative humidity, low socio-economic zones and high population density on the increase in dengue transmission.[21,24,30,40] Some of the articles also found that urban areas with UHI have higher temperatures compared to the surrounding areas and these urban areas showed a high abundance of *Aedes aegypti* in the area of study.[17,27] This can be translated into the potential of dengue transmission due to the increase in the disease vector, which can spread the dengue viruses to the population.

From this review, it was found that the UHI phenomenon characterised by the increase in temperature, changes in land use, vegetation covers, and other climatic factors may influence the dengue transmission and its vector viability in urban areas. Understanding the implications of UHI on the dengue and its vector is crucial especially to public health authorities who are involved in dengue prevention and control activities. Uncontrollable dengue transmission in urban areas may affect a large number of urban residents due to the high population density in urban areas. This led to a high disease burden in the urban areas which may lead to increased cost of treatment and high number of fatality rates. An increase in the transmission of dengue may also overwhelm local public health authorities as dengue prevention and control rely heavily on vector control activities done by public health authorities.[55] Moreover, dengue is a serious public health concern as it continues to spread to new regions, such as Europe, East Mediterranean, and South America, and become endemic in more than 100 countries. Consequently, this may be further transmitted due to UHI effects and other phenomena, such as climate change and global warming.[36,55]

However, there are several limitations to the review, including: 1) The articles reviewed involved study locations from different regions and varying levels of urbanisation which cover different urban area sizes, environmental conditions, urban policy and planning and in-place public health intervention that may affect the dengue incidences over the total population in the urban areas; 2) This review has included articles which are open access and in English language which resulted in less number of articles to be reviewed where the excluded articles may have strengthened the findings of this review; and 3) The criteria and variables of UHI have not been clearly defined causing articles with various variables to be included in the study leading to the generalisation of parameters of UHI in the review. Future reviews and studies may take into consideration the current limitations of this review to further explore the UHI, its parameters, and their implications on dengue transmission and *Aedes* mosquitoes' viability in urban areas. As UHI determination involves various parameters and variables, exploring these variables individually and associating them with dengue transmission and *Aedes* mosquitoes may provide a clear perspective and evidence on the implications of UHI on dengue transmission.

CONCLUSION AND RECOMMENDATIONS

In conclusion, urban heat islands may have significant impact on dengue transmission in the cities which can be seen with the increase in temperature due to urban heat island effects that affect the urban microclimate and influence the *Aedes* density and abundance in the urban areas. Consequently, the increase in *Aedes* density in urban areas may widen dengue transmission leading to an increase in the dengue disease burden in these areas. Concurrently, other climatic factors (e.g., precipitation and relative humidity) and land use/land cover variables (e.g., LULC, NDVI) also play significant roles in dengue transmission as they provide a suitable environment for the growth and survival of *Aedes* mosquitoes in the urban areas. In controlling the transmission of dengue in urban areas, strategies must be planned and implemented that include urban planning and dengue control programmes. Future towns and cities must be planned in alignment with the Sustainable Development Goals (SDGs), such as Sustainable Development Goal 11 (SDG 11) (Sustainable Cities and Communities), which targets to make cities and human settlements inclusive, safe, resilient, and sustainable. There must be an integration between dengue control and prevention programmes in the town planning, which requires health and local authorities working together in implementing integrated vector control management to eliminate potential *Aedes* breeding grounds that can potentially result from urbanisation and development activities. Moreover, urban design must take into consideration the effect and mitigation measures of climate change and global warming due to its effect on the urban microclimate, leading to an increase in temperatures that can influence the life cycle of *Aedes* mosquitoes and subsequently affect dengue transmission in the cities. In addition, it is recommended that more studies be conducted to determine the implications of urban heat island effect on dengue incidence particularly using indicators such as urban heat island intensity (UHII), daytime and nighttime temperatures, population density, and socio-economic characteristics as the study variables to further understand the impact of UHI on dengue transmission in urban areas.

CONFLICT OF INTEREST

There is no conflict of interest to declare.

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